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Consolidation Treatments for the Alveolar Erosion of the Agrillaceous Sandstone at Durham Castle

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Abstract
The thesis addresses possible consolidation treatments for the sandstone masonry of Durham Castle, a UNESCO World Heritage site located in Durham, England. The historic masonry is made of an argillaceous sandstone that suffers a unique deterioration phenomenon known as alveolar erosion. Alveolar erosion is a problem that relates to the geo-chemical nature of the stone, particularly the presence of swelling clays. Two treatments were considered in this thesis: a plain ethyl silicate (Prosoco OH100), and an elastified ethyl silicate (Remmers KSE 300 E). The performance of each treatment was compared through laboratory testing of the following properties: water absorption and drying, water vapor permeability, color changes, scanning electron microscopy, and drilling resistance measurements. Testing showed that both treatments increased the hardness of the stone, however the stone treated with Conservare OH100 exhibited the greatest increase. Both treatments changed the wetting and drying behavior and the water vapor transmission, with the Remmers KSE 300 E treatment altering the stone slightly more. Through scanning electron microscopy it was shown that both consolidants showed poor adhesion to mineral grains and that Remmers KSE 300 E provided a more uniform coverage than Prosoco OH 100. The application of the latter darkened the surface color of the stone.

This thesis shows that there are advantages and disadvantages to each treatment and that additional research is needed to determine if ethyl silicate consolidation will be an effective treatment. Further analysis is needed to determine correlation between binder composition and deterioration. Additionally, it is recommended that pre-treatments, including an anti-swelling agent and adhesive coupling agent be tested in conjunction with the ethyl silicate consolidants.

Keywords
argillaceous, sandstone, consolidation, drill resistance, sandstone, ethyl silicate

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CONSOLIDATION TREATMENTS FOR THE ALVEOLAR EROSION OF THE AGRILLACEOUS SANDSTONE AT DURHAM CASTLE

Mary Catherine Collins

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Chapter 1: Introduction

1.1 Historic Background

Durham Castle, originally constructed as a Norman fortress is located on a peninsula on the River Wear in northeast England. The castle forms part of an 11th century medieval cityscape that in conjunction with Durham Cathedral, was added to the UNESCO World Heritage List in 1986. It is the largest intact example of Norman architecture in England. Construction of the castle began in 1072 under a commission by King William the Conqueror. Until 1837, it housed the Prince Bishops of Durham, when it was donated to Durham University. It is still in active use by Durham University today.[1]

Figure 1.1 Durham Castle (Simple, 2009).

[1] An account of Durham's history and architectural significance can be found in the UNESCO World Heritage description as well as in: Brickstock, Richard. *Durham Castle: Fortress, Palace, College.* West Yorkshire:Jeremy Mills Publishing, 2007. Print.

The castle is constructed of locally quarried fine to medium grain sandstone laid in both plain and carved ashlar blocks. The deterioration of its exterior stonework has been of concern since at least the early 20th century, when documented repairs in the form of structural pinning and cement patching of the ashlar blocks took place. Additionally, photographic evidence from the early 20th century shows the deteriorated condition of the exterior masonry. In 1999, the castle was placed on English Heritage's 'Buildings at Risk' register and described as "suffering slow decay; no solution agreed" to highlight the plight of the building in hopes of facilitating financial means for its conservation.[2] Today, the conservation of the exterior masonry is an important concern to its stewards, as its deterioration threatens one of England's greatest architectural treasures.

1.2 Problematic Issues

While the exterior masonry walls at Durham Castle suffer from various deterioration mechanisms, the most significant and damaging is alveolar erosion (see Figure 1.2). Alveolar erosion is defined as the localized pitting of a stone surface due to loss of the inter-granular cohesion.[3] The loss of inter-granular cohesion usually results from the loss of cementing matrix of the stone, leading to the wholesale collapse of masonry units.

Alveolar erosion is a historic problem at Durham Castle and limited interventions have been implemented in the past. These include composite repair and full replacement

[2] Brickstock, Richard, 2007.
[3] Anson-Cartwright, T., V. Vergès-Belmin. *Illustrated glossary on stone deterioration patterns, english-french version*. 2008. < http://www.cicrp.fr/docs/icomos-iscs-glossary.pdf>.

of masonry units. Composite repairs address surface loss; however, in an advanced stage, alveolar erosion forms deep cavities in the stone and the masonry unit becomes structurally unstable. Currently, replacement is the most common approach employed at Durham Castle. Proving that stone consolidation is a viable option would provide an alternative conservation method for the sandstone deterioration problem. In principle, it would retard the deterioration rate of the masonry so that it would take far longer to require full unit replacement. Consolidation has the potential to preserve original unit masonry and in particular, artistic and historic elements, such as carvings and tool marks.

Figure 1.2 Alveolar erosion at Durham Castle (Simple, 2009).

In 2010, a research thesis at the University of Pennsylvania established that the alveolar erosion observed at Durham Castle is a result of the geo-chemical nature of the stone and other environmental factors.[4] The presence of swelling clays, such as

[4] Simple, Tiffani. *Alveolar Erosion and its Conservation Recommendations for the Sandstone Masonry at Durham Castle* Graduate Thesis. Philadelphia: The University of Pennsylvania, 2010.

montmorillonite, and of soluble salts, such as gypsum, in combination with the frequent wet-dry cycling of the stone, enhanced by increased evaporation due to windy conditions and the consequent salt recrystallization cycles, all contribute to this severe deterioration.

1.3 Possible Solutions

The present thesis aims to evaluate selected consolidants for the treatment of alveolar erosion of the sandstone masonry at Durham Castle. For this purpose, two ethyl silicate consolidants, Conservare OH100 (Prosoco) and an elastified ethyl silicate consolidant, KSE 300E (Remmers) were selected for evaluation. The performance of each consolidant will be determined by laboratory testing of the following properties: mechanical strength, water vapor permeability, and water absorption and drying, as well as evaluation of the depth of penetration of the consolidant. If identical property tests are carried out on parallel samples treated with either an elasticized or a non-elasticized ethyl silicate consolidant, then it will be possible to compare the effectiveness of the two products for this particular stone. For example, the treatment that imparts the greater mechanical strength increase, fully and homogenously penetrates the decayed zone of the stone without resulting in significant behavior differences between treated and untreated zones, and does not significantly alter the water vapor permeability or wetting and drying behavior of the stone, would be considered to be the most appropriate treatment.

Chapter 2: Alveolar Erosion and Deterioration

2.1 Introduction

In the master's thesis by Tiffani Simple (2010), it was observed that replacement masonry comprised 79% of the east façade at Durham Castle, reflecting the extent of deterioration.[5] Over seventeen different deterioration conditions were recorded on this elevation of Durham Castle.[6] Of these, alveolar erosion has long been recognized as the most serious condition, also referred to as honeycomb weathering, tafoni, stone lattice, or cavernous weathering (the name usually dependent on the size of pit). Alveolar erosion is a result of the displacement of mineral grains and loss of the inter-granular cohesion of the stone, eventually leading to collapse of the masonry unit.[7]

Figure 2.1 Alveolar erosion at Durham Castle (Simple, 2009).

[5]Simple, Tiffani. *Alveolar Erosion and its Conservation Recommendations for the Sandstone Masonry at Durham Castle* Graduate Thesis. Philadelphia: The University of Pennsylvania, 2010.
[6]In 2009 Simple and her colleague completed an on-site assessment of the east elevation of Durham Castle. Each deterioration pattern was recorded and quantified using rectified photography, AutoCAD, and Arc GIS. See Simple, 2010.
[7]Anson-Cartwright, T., V. Vergès-Belmin. *Illustrated glossary on stone deterioration patterns, english-french version*, 2008 < http://www.cicrp.fr/docs/icomos-iscs-glossary.pdf>.

2.2 Stone Characterization: Visual Observations

For the purposes of this thesis, a weathered ashlar block exhibiting alveolar erosion was obtained from Durham Castle for analysis and testing. In the course of testing, the block was cut perpendicular to the alveolus. The cuts revealed a concentration of iron oxide (evident by its orange color), following the curvature of the alveolus. At first glance, this orange band does not appear to be part of the bedding pattern, as clear bedding divisions are visible perpendicular to it. Sandstones can be cross-bedded, but it is likely that this iron-rich area is a result of mobilized ferrous oxide (as Young postulated).[8] The petrographic thin sections of pitted areas appeared to have more iron oxide than the thin section of less weathered areas (see section 2.3). The iron content was not quantified and should be included in future studies. Future studies should also include X-Ray powder diffraction on samples from areas of concentrated iron oxide and from an area outside of the iron oxide band. This would provide comparative information about the various iron minerals present in the two areas that perhaps could explain the mobilization of iron within the sample.

Micro-cracking was visible at the base of the alveolus, and followed the curvature of the alveolus, resembling the beginning of detachment. Most hypotheses into the cause of alveolization begin with localized detachment that continues to disaggregate into a pit. These observations show that the alveolar erosion, as observed at Durham Castle, follows patterns similar to those described in the current geology and masonry conservation literature.

[8]Young, Ann R.M. "Salt as an agent in the development of cavernous weathering." *Geology*, v15, i10. (1987): 962-966. Web Feb. 2012. <http://geology.geoscienceworld.org.>

Figure 2.2 Dashed line shows the edge of iron oxide banding beneath the weathered cavity.

2.3 Stone Characterization: Optical Microscopy

Polarized light microscopy was employed to gain an understanding of the texture and main minerals present in the samples. This was carried out on samples prepared in thin section, thus allowing light to pass through the grains. Individual mineral grains can be identified through this technique, but more importantly, characteristics such as porosity, variations in the amounts of the various minerals, and physical and chemical alterations to the grains can be observed. By use of a polarizer, mineral grains can be identified by differences in their refractive index and absorption color.

2.3.1 Methodology

Re-examination of two sandstone samples from Durham was carried out on four thin sections that had been prepared in 2010 for a previous thesis.[9] The thin sections were taken in pairs from two different samples exhibiting alveolar erosion to different degrees; one with significant deterioration and the other, with incipient alveolization. From each stone, one thin section was prepared from a cavity surface and the other from a less weathered area. Thin sections were mounted in cross section so that additional comparisons could be made between the inner stone and the weathered surface. Additionally, the thin sections were injected with blue epoxy to assist in pore space identification. Thin sections were examined using an Olympus CX31 polarizing light microscope. While general observations on the nature of the stone could be made, it quickly became evident that a wider spectrum of samples would be needed to complete a more thorough investigation into the causes of alveolization in this particular stone.

Table 2.1 Thin section sample identification

Thin Section ID	Sample location
A	weathered surface (not a cavity) bulk sample "A"
A_C	cavity surface of bulk sample "A"
B	weathered surface (not a cavity) bulk sample "B"
B_C	cavity surface of bulk sample "B"

[9] Simple,Tiffani. 2010.

2.3.2 Observations

Thin sections from both samples, A and B, show clay-rich sandstone of immature sedimentation. The quartz grains exhibit a weak lithification process of compaction, with some suturing of quartz grains. The Durham sandstone is fine-grained with inclusions of iron oxide, mica, and feldspar. The pore space is made evident in the thin sections by the blue color of the epoxy used to prepare them. Quartz grains typically show as white polygons with their boundaries defined by thin lines. The spacing of the boundaries indicates the lithification process and whether the quartz is compacted, fractured, or sutured. The areas that are dark brown or black could represent iron minerals. Areas that do not fit the above descriptions and appear "muddy" are likely to be clays, particles that are too small to see using this technique.

Sample B_C exhibits micro-cracking, sub-angular quartz grains, and more clay than the A_C sample. Sample B_C also might reflect an example of case hardening as the porosity changes near the surface of the stone. However, due to the poor preparation of the samples and lack of other samples for comparison, this speculation needs confirmation by additional examination of equivalent samples. Sample B, taken from the edge or a cavity, exhibits possible surface disaggregation. The quartz grains appear to have been once compacted, but are now separated by spaces between them. Sample B_C, taken from the cavity, shows a higher porosity and higher iron content than sample B, taken from a weathered surface that does not exhibit alveolar erosion. Additionally, one can see a difference of porosity between the surface and interior area of the thin section. As observed through

polarizing light microscopy, it can be concluded that alveolar erosion is the result of loss of the cementing matrix. Since part of the matrix may be calcareous and partly ferrugineous clays, different mechanisms will be operating. Chemical dissolution by air pollutants of the calcareous matrix will result in the formation of gypsum contributing by the crystallization cycles of the latter to form the pits. Argillaceous matrices, on the other hand will be susceptible to expansion-contraction of these minerals during wet-dry cycles.

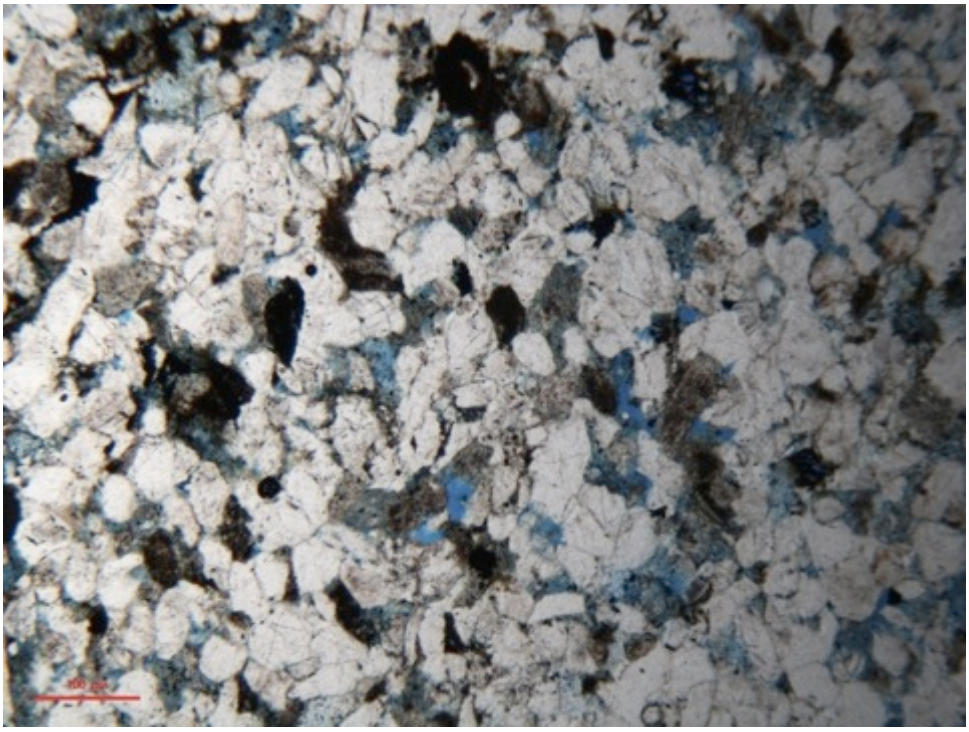

Figure 2.3 Photomicrograph at 4x of sample "B" in plane polarized light showing general porosity and grain size. The white area is likely quartz, the dark brown or black areas are iron and the blue area represents pore space.

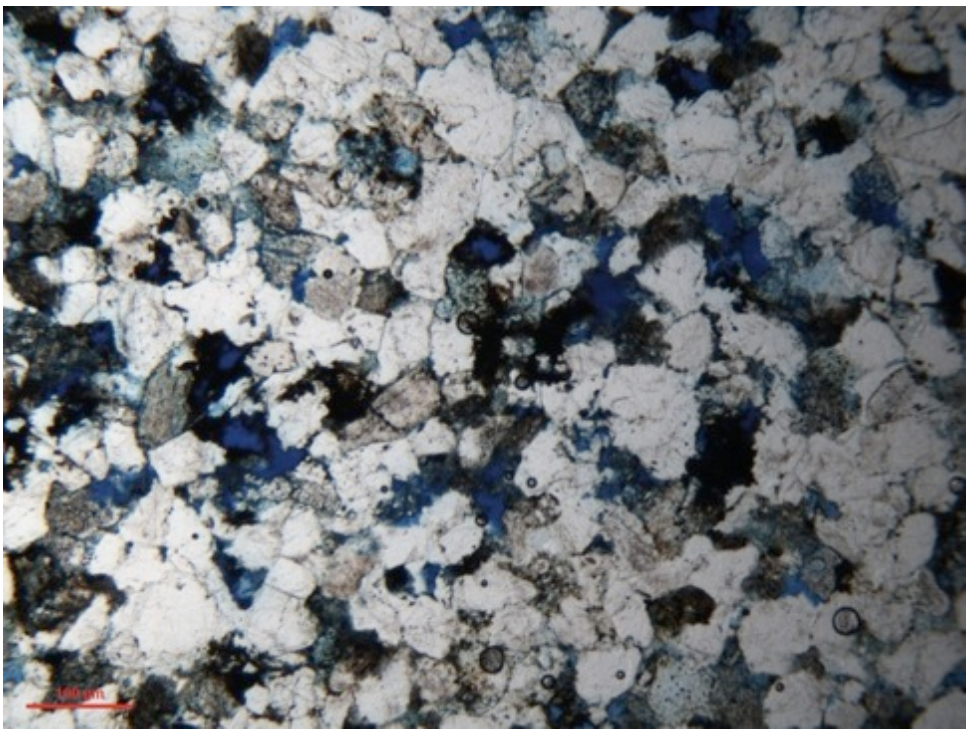

Figure 2.4 Photomicrograph at 4x of sample “B_C” in plane polarized light showing general porosity and grain size of sample "B_C". It has larger pore space and iron oxide bordering the pores.

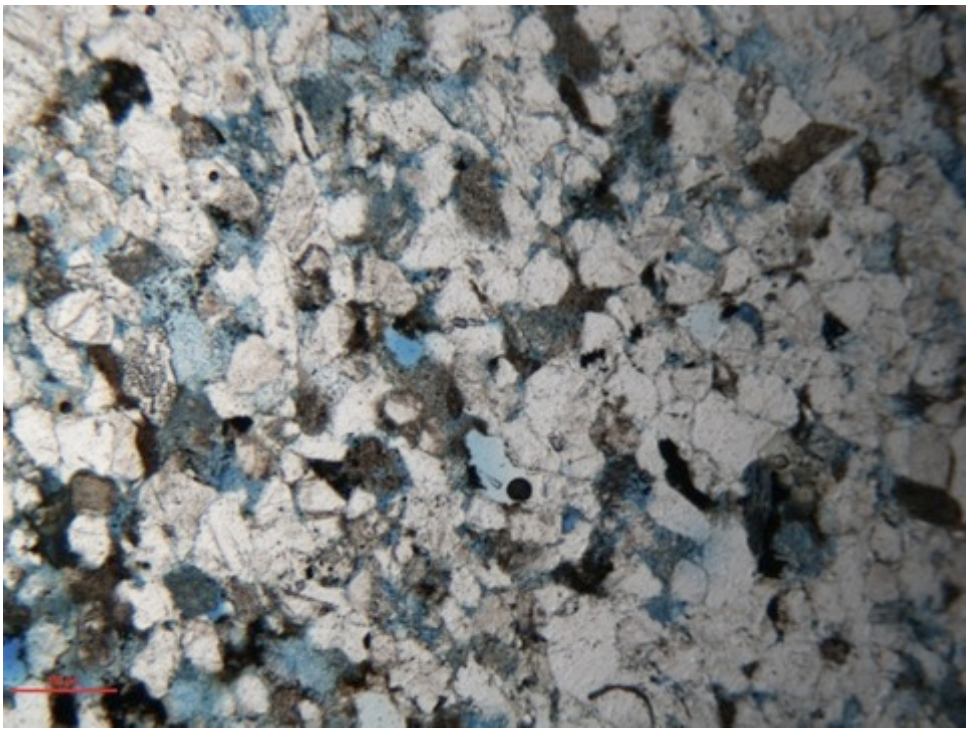

Figure 2.5 Photomicrograph at 4x in plane polarized light near the surface of sample “B” showing general porosity, which appears to be less than that of sample “B_C”. Note that there is not a high quantity of iron visible.

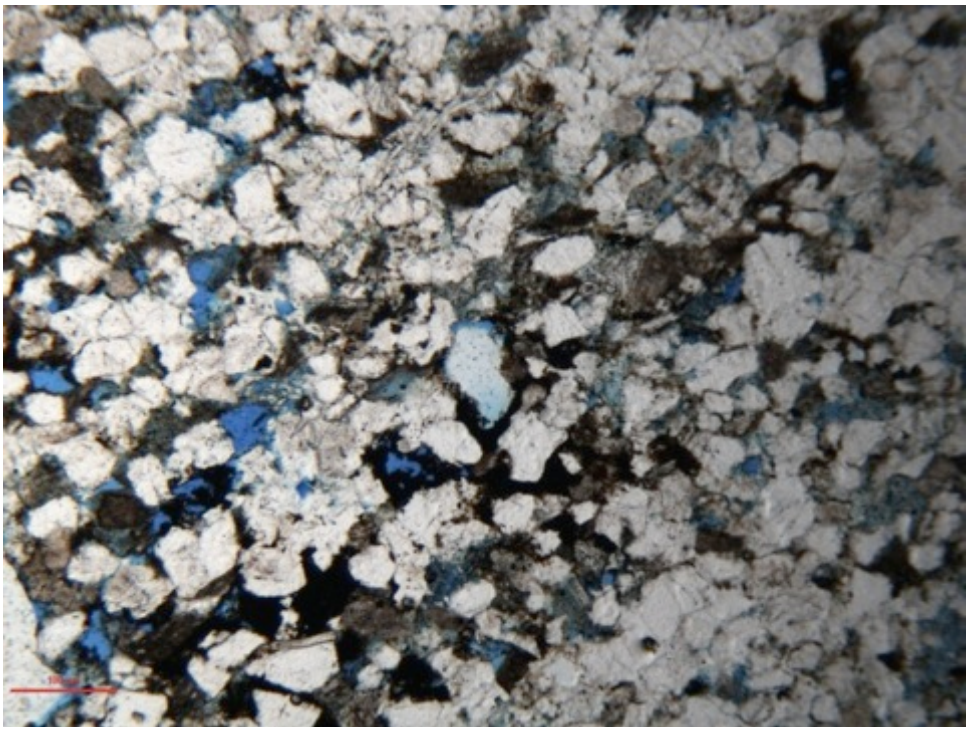

Figure 2.6 Photomicrograph at 4x at the surface of sample "B_C" in plane polarized light showing possible disaggregation at surface; evident by increased porosity and detached quartz grains (left portion of image).

2.4 Alveolar Deterioration

Currently, there are several theories as to what factors contribute to alveolar erosion. As with most forms of masonry deterioration, it is a combination of the geochemical composition of the stone, the presence of soluble salts, and environmental conditions. The latter include such factors as wind, wetting and drying cycles, and proximity to seawater. In masonry, the mortar types used in the setting of the stonework may be relevant because they may release soluble salts or generate them with air-pollution. Often overlooked (or perhaps taken for granted) is the study of sedimentation processes and the resulting stratigraphy patterns within the stone. Bedding strata can directly correlate to areas of damage.

Most studies on the geochemical nature of sandstone focus on the quantity and

type of clays in the cementing matrix that may also be partly calcareous, the size and shape of quartz grains, and the type and quantity of other minerals present, such as feldspar and iron oxides. Porosity, grain size differences, and evidence of lithification are also typically examined. The presence of salts is an important contributing factor in stone deterioration and therefore it is important to know whether they are present and if so, identify the type as well as the amount of all salts present. A qualitative analysis with salt test strips can only determine the type(s) of anions present. To identify the actual salt(s) present, other tests need to be carried out such as X-Ray powder diffraction, polarized light microscopy, and ion analysis (can be accomplished using semi-quantitative test strips). Alveolar erosion will result from the combination of the particular geochemical nature of the stone, when soluble salts are present and in given environments, both at inland and coastal sites.

It has been shown that in coastal environments the deposition of sodium chloride contributes to alveolar erosion.[10] On inland sites, other salts may be the contributing factor and analyses, such as those listed previously, are required to identify the salt or salts present. For example, Siedel completed analysis of Cretaceous sandstone in Saxony, Germany and determined that the presence of magnesium sulfate and gypsum were contributing to alveolar erosion in combination with a clay matrix and wetting and drying patterns.[11] In this study, it was determined that magnesium sulfate was concentrating in areas of high clay content. Once the crystallization of magnesium sulfate has created

[10] Dragovich, D. "Weathering of sandstone tombstones in a coastal environment, Sydney (Australia)." *The Engineering Geology of Ancient Works, Monuments and Historical Sites.* Eds. Paul G. Marions and George C. Koukis. Rotterdam: Balkema, 1988. 853-858.

[11] Siedel, Heiner. "Alveolar weathering of Cretaceous building sandstones on monuments in Saxony, Germany." *Natural Stone Resources for Historical Monuments*. Eds. Prikryl, R. and A. Torok.The Geological Society of London Special Publications v 333, 2010. 11-23.

initial pitting on the surface, magnesium sulfate will continue to concentrate at the bottom of the pit as this area dries more slowly than the edges of the pit. At this point, the erosion is a "self-perpetuating process…dependent only on changing moisture and climate".[12] In addition gypsum, a fairly insoluble salt, [13] concentrates at the edges of the pits while magnesium sulfate remains solubilized in water and moves to the slowest drying area, the base of the pit, where it eventually crystallizes and causes continuous and localized damage.

The presence of expansive clays could also contribute to alveolar deterioration, especially it they are found in pockets within the stone. All clays expand in the presence of water, however highly expansive ones, such as the montmorillonite group, are capable of taking up a lot more water and swelling significantly thus inducing the damage. Two processes have been identified for this expansion: crystalline and osmotic swelling. Crystalline swelling is a result of the cations between silicate and aluminate layers attracting water molecules and imposing an expansive force. These forces are a lot higher than those resulting from osmotic swelling, which is the result of an ion concentration difference between the surface of clay layers and the pore water.[14]

For a stone with alveolar erosion, the pit, or alveolus, dries differentially — the base of the pit typically dries the slowest and clays theoretically remain in their expanded state longer allowing for the dislocation of silica grains. If salts are present, they will tend to concentrate in this area and contribute to delay the drying process by retaining moisture. It is important to note that in the presence of salts, the contraction and

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[12]Siedel, 2010.
[13]Charola, E., J. Pühringer, and M. Steiger. "Gypsum: a review of its role in the deterioration of building materials." *Environmental Geology v52, i2,* 2007. 339-352.
[14]Madsen, Fritz T. and Max Müller-Vonmoos. "The Swelling Behaviour of Clays." *Applied Clay Science*, v4 1989.143-156.

expansion of clays are altered, that is, they contract upon wetting and expand upon drying but this process is far more irreversible than that suffered by clays alone.[15] For these reasons, salts and moisture can be understood as contributing to alveolar erosion.

For a pitted surface, this can happen even when the rest of the stone is mostly dry. The retention of humidity not only affects the expansion of clays, but also allows for the capillary transport or diffusion of soluble salts. These salts will eventually crystallize and have the potential to cause damage after one or many wetting and drying cycles. Siedel's analysis of alveolar erosion advances the current knowledge beyond re-stating the general factors contributing to stone deterioration, such as wind and salt crystallization, and seeks to explain the unique trait of alveolar erosion: deterioration in the form of pitting that occurs in localized areas; or looking at it from another perspective, the preservation of thin walls between cavities.

It has also been suggested that once a pit is begun on a masonry surface, a type of micro-climate is created within the pit, in which wind can exert a greater force and differential pressure, aiding in the mechanical weathering of the sandstone. In some studies, conchoidal fracturing of quartz seems to suggest that mechanical damage is taking place due to weather conditions or micro-climates.[16] Mustoe demonstrated that most cavities occur along bedding and joint planes, but it is clear that something else is working in synergy because the damage results not in delamination or detachment, but deep, cavernous pits. He suggests that dissolution and re-deposition of iron minerals

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[15]Snethlage, R. and E. Wendler. "Moisture Cycles and Sandstone Degradation." *Saving Our Architectural Heritage: The conservation of historic stone structures: Report of the Dahlem Workshop on Saving Our Architectural Heritage*, *Berlin March 3-8, 1996.* Eds. N.S. Baer and R. Snethlage. New York:John Wiley & Sons, 1997.

[16]Brandmeier, M. J. Kuhlemann, I. Krummel, A. Kappler, and P.W. Kubik. *Earth Surface Processes and Landforms, v. 36, i.6,* 2011. 839-852.

contributed to case hardening in his study of rock formations in a coastal environment.[17]

Mustoe's proposition that mobilized iron minerals occur concurrently with alveolar erosion is corroborated by Young, who proposed that alveolar erosion is a result of chemical processes. In this theory, salt does not physically force apart grains, but plays an assisting role in dissolving the cementing matrix of the sandstone and thus leaving the silica grains separated and without a binding material.[18] Salt such as sodium chloride, can accelerate the rate of silica dissolution.[19] Further, Young points out that acidic water can mobilize ferrous oxide within the stone.

2.5 Durham Castle and Alveolar Erosion

It is likely that together, the presence of soluble salts and the swelling behavior of clays contribute to alveolar erosion. Additionally, iron oxide banding indicates that iron is preferentially segregated by bedding layer and might play a role in deterioration.

Simple used optical microscopy to identify an apparent porosity of 13% and a clay matrix accounting for 14% of the sample for a "less weathered sample". This is in contrast to her findings on a weathered sample, taken from a pitted surface, for which she observed a porosity of 28% and 19% clay matrix. Through scanning electron microscopy, Simple observed a significant amount of clays in the sandstone masonry at Durham Castle. X-Ray powder diffraction (XRD) analysis found that illite and montmorillonite comprised 20% of the mineral composition. While only montmorillonite is the expansive

[17]Mustoe, G.E. "The Origin of Honeycomb Weathering." *Geological Society of America Bulletin, v93.* 1982. 108- 115.
[18]Young, Ann R.M. "Salt as an agent in the development of cavernous weathering." *Geology*, *v15, i10.* 1987. 962-966. Accessed via Geology online at <http://geology.geoscienceworld.org.>
[19]van Lier, J.A., de Bruyn, P.L., and Overbeek, J. "The solubility of quartz." *Journal of Physical Chemistry v.64,* 1960.1675-1682.

clay, it can form mixed-layer clays with illite, and these are also expansive. The remaining clays identified using XRD were dickite and kaolinite.[20]

Simple's semi-quantitative analysis of soluble salts showed that the sulfate ion content of weathered stone ranged between 0.34% and 0.67% by weight and that this corresponded to gypsum ($CaSO_4,2H_2O$) since this salt alone accounted for the total soluble salts present in the samples. She could correlate content to length of exposure, weathered samples containing a higher salt content than unweathered samples, as would be expected from exposure to air pollution.[21]

If salts are not a result of wind and rain deposition, they could be a result of chemical reactions from pollutants, such as sulfur dioxide, with the lime from mortars (as might also be the case for gypsum), or the calcareous binder in the sandstone itself. By observing the distribution pattern of salts within the stone, it could be possible to theorize their origins and the process through which they contribute to the stone's decay.

No chlorides were found and because Durham Castle sits approximately twenty kilometers west of the North Sea and receives prevailing winds primarily from the southwest it is unlikely that sodium chloride is a factor for alveolar erosion at Durham, although this needs confirmation through further analysis. However, it is plausible that prevailing winds deposit sodium chloride from the Irish Sea, which lies to the west. More accurate weather data and ion analysis salts within the Durham sandstone would confirm or refute this hypothesis. Since salt and wind in combination with the geological makeup of the stone have been found to be enough to cause alveolar erosion, relationships between the nature of the stone, the salt(s) present and the environment should be further

[20] Simple, 2010.
[21] Ibid.

investigated at this site.[22]

Analysis by SEM-EDS that sodium (Na) was present in the three areas of stone sampled, with the highest percentage in the area where alveolar erosion had occurred. Aluminum (Al) was also identified, with highest concentrations on the area described as "flaky". Lastly, magnesium (Mg) was reported for the "flaky" sample and the sample taken from a "planar" or "flat" area, but not included in the analysis of the sample exhibiting alveolar erosion. All of these elements are found in either the clays or feldspars present.

In conclusion, it is evident that the alveolar deterioration suffered by the sandstone at Durham Castle is a problem that relates to the nature of the stone, particularly the presence of swelling clay. The gypsum that has accumulated over the years further exacerbates the issue of the swelling clays. While the reason for the development of the alveolar pattern is yet to be elucidated, the information obtained point towards possible treatments methods that could be applied to mitigate the problem.

[22]Siegesmund, Siegried and Rolf Snethalge. *Stone in Architecture Properties, Durability*, Fourth Ed. Berlin: Springer, 2011.

Chapter 3 Consolidation Treatments

3.1 Introduction

The products chosen for testing on the Durham sandstone are Conservare OH100 and Remmers KSE 300 E. Conservare OH100 is a plain ethyl silicate, while Remmers KSE 300 E is an elastified ethyl silicate consolidant.

Both consolidants are designed to slow down the decay of stone through the restoration of intergranular cohesion. This is accomplished by the deposition of a silica gel into the intergranular spaces. While this amorphous material is compatible with the nature of the sandstone, based primarily on quartz, clays, some plagioclase and feldspar, and minor calcite binder, laboratory testing is still required to ensure the effectiveness of the deposited material as a consolidant. By comparing a plain ethyl silicate and an elastified ethyl silicate, it is hoped that recommendations can be made regarding the possible use of one or the other at Durham Castle.

3.2 Ethyl Silicate Consolidants

The use of ethyl silicates as a consolidation treatment for stone has been of interest in the conservation field since its suggested application on the Houses of Parliament in London by A.W. Hoffman in 1861.[23] Its popularity for conservation has only increased since that time, as further improvements in its formulation have enhanced its consolidating properties.

Ethyl silicates have the ability to restore inter-granular cohesion in stone through the formation of siloxane bonds (Si-O-Si) using a process of hydrolysis, condensation

[23] Wheeler, George. *Alkoxysilanes and the Consolidation of Stone.* Los Angeles: Getty Publications, 2005.

and polymerization. Hydrolysis results from the reaction of these compounds with moisture including that retained by the pores of the stone. Silanol, a result of the hydrolysis process, then polymerizes through condensation to create a "gel" that possesses the hardy traits of the silicate minerals that naturally occur in stone, including lightfastness, oxidative stability, and bond strength.[24]

Ethyl silicates are often mistakenly referred to as a type of alkoxysilane. An alkoxysilane refers to a compound containing at least one silane bond, i.e., either Si-H or Si-C, with the rest being siloxane bonds, i.e., Si-O-C, that are capable of hydrolysis and polymerization. The alkoxysilanes employed most frequently in stone consolidation are methyltriethoxysilane (MTEOS) and methyltrimethoxysilane (MTMOS). The alkyl group bonded directly to the silicon, i.e., the silane bond (Si-R) where the R stands for the methyl group in the above compounds ($Si\text{-}CH_3$), confers hydrophobicity to the compound and to the resulting polymer.

Tetraethoxysilicate (TEOS), or ethyl silicate, is often grouped in this category and inaccurately called tetraethoxysilane. It has four Si-O-R groups, where R is an alkyl group such as methyl ($-CH_3$) or ethyl ($-C_2H_5$), making it a silicate (as there is an oxygen atom between the Si and the alkyl group), and not a silane (see Table 3.1). Because these compounds contain four alkoxy groups (three in the case of the alkyl trialkoxy silicates), they have the ability to form three-dimensional networks, which creates a solid network of bonds for consolidation.

The consolidants MTEOS, MTMOS, and TEOS possess several traits favorable to stone conservation: they have a low viscosity, hydrolize at a reasonable rate due to the catalyst included in the formulation, and only produce alcohols as volatile byproducts

[24] Smith, A.Lee. *Analysis of Silicones*. Florida: R.E. Krieger, 1983.

that are eliminated. A low viscosity permits the chemical to penetrate the pores and inter-granular network of a stone, increasing its ability to effectively consolidate the material. The rate of hydrolysis is significant; for if a consolidant were to hydrolize too quickly, it could gel before it has penetrated the stone to a significant depth, leading to ineffective results or additional damage to the stone. Lastly, for the safety of the conservator and preservation of the stone, it is important that consolidants do not produce damaging byproducts during their hardening process. In the case of the aforementioned consolidants, the hydrolysis byproducts are alcohols and not damaging to the stone or conservator, except for the MTMOS where methanol is liberated.[25]

Of the consolidants available, TEOS, or ethyl silicate, is perhaps most commonly used because it is commercially available and can easily be applied. It is formulated with various catalysts and additives; in the commercially available Conservare OH100, di-butyltindilaurate is listed as an additive and serves as catalyst, and ethyl alcohol as the solvent.

Table 3.1 Common compounds for stone consolidation

Chemical name	**Abbreviation**	**Molecular formula**
Tetraethoxysilicate, often misnamed as tetraethoxysilane	TEOS	$Si(OCH_2CH_3)_4$
Methyltriethoxysilane	MTEOS	$CH_3Si(OCH_2CH_3)_3$
Methyltrimethoxysilane	MTMOS	$CH_3Si(OCH_3)_3$

[25] Smith, 1983.

Laboratory and in-situ tests have shown the strengthening effects of ethyl silicate on sandstone using compressive and flexural strength tests as well as non-destructive assessments, such as ultrasonic pulse velocity.[26] [27] [28] [29] While ethyl silicate has been proven to have a strengthening effect on sandstone, its durability after the stone is subjected to weathering will depend on many factors and cannot be predicted a priori. Data on the effect of weathering on treated sandstone is limited by the fact that few conservators return to a site to evaluate its performance in the long term.[30]

3.3 Consolidant Application

It is clear that the pore network, in terms of pore size, distribution, and connections can influence the effectiveness of a consolidant. The porosity of a stone can determine the force of capillary action that draws the liquid consolidant through the stone matrix. Other factors that can alter the efficacy of a consolidant are the other mineral components present apart from the main quartz content of the stone itself, such as feldspar and calcite, and the clay binder, past treatments, and the method(s) employed in its application, including ambient humidity. The presence of soluble salts within the stone,

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[26] A set of "typical German sandstones" exhibited a flexural strength increase through the application of silicate ester and modified silicate ester in a laboratory test in: Boos, M, J. Grobe, G. Hilbert, and J. Muller-Rochholz. "Modified elastic silicic-acid ester applied on natural stone and tests of their efficiency." *8th International Congress on Deterioration and Conservation of Stone*. Ed. Josef Riederer. Germany:Möller Druck and Verlag, 1996. 1179-1185.

[27] Watsamtacjad, Nuanlak. *An Investigation of Sandstone Consolidation Method for the Northern Gopura of the Phimai Sanctuary, a Khmer Monument in Thailand*. Graduate Thesis. The University of Pennsylvania, 2001.

[28] Compressive strength increase demonstrated on a porous sandstone in:
Grisafe, David A. "Potential Preservation of Native American Petroglyphs at Steamboat Butte, Montana, Using Ethyl Silicate Solution Treatments." *The Plains Anthropologist v47, n180.* February 2002. 77-84. Accessed via <http://www.jstor.org/stable/25669753>.

[29] Oliver, A. "The variable performance of ethyl silicate: Consolidated stone at three National Parks." *APT Bulletin v33 n.2/3*. 2002. 39-44.

[30] Hallock, P. Gardine. "Assessing Past Conservation Treatments at George Washington's Mount Vernon." *APT Bulletin, v33, n.2/3,* 2000.15-22. Accessed via <http://www.jstor.org/>.

which can mobilize even after consolidation by ethyl silicate, can continue to induce subsequent damage. Costa and Delgado Rodrigues have shown that ethyl silicates do not encapsulate salts within select granites.[31] Therefore, it is important to carry out laboratory testing on the stone to be treated to fully understand the capabilities of an ethyl silicate treatment on a particular stone. In the case of Durham, Simple identified gypsum as the primary salt. Gypsum is the least soluble of the so-called soluble salts, and therefore not as damaging as the more soluble salts. Nonetheless, it should be further studied and perhaps immobilized by a prior treatment with barium hydroxide to prevent its crystallization cycles.

Another factor that can affect the outcome of consolidation on sandstone is the presence of clays. The sandstone of Durham Castle contains a clay binder of mostly illite and montmorillonite, the latter being the most expansive in the presence of moisture followed the possible mixed layer clays that it can form with illite. Using SEM analysis, it has been shown that in some sandstones ethyl silicates do not adequately cover clay particles and that the consolidant bonds are easily destroyed through hygric expansion. This results in additional microcracking of cured consolidant and renders the treatment ineffective in as few as 4-10 weathering cycles.[32] The proposed alternatives for dealing with clays involve pre-treatment with an antiswelling agent, a sort of surfactant, and the use of elastified ethyl silicates.[33] [34]

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[31] Costa, Dória and José Delgado Rodriguez. "Consolidation treatment of salt laden materials. Methodology for their laboratory study." *11th International Congress on Deterioration and Conservation of Stone.* Eds. J. Lukaszewicz and P. Niemcewicz. Tourun:Nicolaus Copernicus University Press, 2008.
[32] Wheeler, 2005.
[33] Snethlage, R. and E. Wendler. "Surfactants and adherent silicon resins – new protective agents for natural stone." *Materials Issues in Art and Archaelogy, II*. Eds. P. Vandiver, J. Druzik, and G. Wheeler. Pittsburgh: Materials Research Society, 1991. 193-200.
[34] Wendler, E. "New Materials and Approaches for the Conservation of Stone." *Saving Our Architectural Heritage: The conservation of historic stone structures: Report of the Dahlem Workshop on Saving Our*

3.4 Elastified Ethyl Silicates

Elastified ethyl silicates are a more recent improvement of the plain silicate ester consolidant. Elastification is attained by the insertion of linear siloxane segments within the ethyl silicate polymer so that upon curing, the polymer is not as rigid. Within a plain silicate ester, the lattice-like structure creates rigidity, but by lengthening the distance junctions between these lattice-like compounds, the polymer can become more flexible. Snethlage and Wendler (1991) describe the linear insertion as being able to "rotate". The objective of elastification is to reduce the amount of cracking that occurs during polymerization reaction and subsequent drying phase of the formed gel.[35] Cracking is a result of inelasticity of the consolidant and of capillary force exerted on the gel by the interstitial pores. It provides secondary porosity, thus avoiding "sealing" of the stone, and can be observed under SEM examination, as shown subsequently.

The secondary porosity created by micro-cracking helps maintain acceptable wetting and drying behavior of the stone. However if these cracks are too wide, the consolidant will be unable to bridge large gaps between grains, thus decreasing the overall strength of the consolidated area.

Remmers, in their product literature states that the elastified ethyl silicate product, KSE 300 E, can sufficiently increase stone strength while maintaining a higher E-modulus than a traditional ethyl silicate consolidant. Elastified ethyl silicates were first produced and examined in the 1990's. They were produced by introducing an organic

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Architectural Heritage, *Berlin March 3-8, 1996.* Eds. N.S. Baer and R. Snethlage. New York:John Wiley & Sons, 1997.

[35] Zarraga R., Cervantes J., Salazar-Hernandez C., Wheeler G. "Effect of the addition of hydroxyl-terminated polydimethylsiloxane to TEOS-based stone consolidants." *Journal of Cultural Heritage* v11 i2, 2010. 138-144. Web April 2012. <http://www.sciencedirect.com/science/article/pii/S1296207409001071>.

additive and hydroxy-terminated polydimethylsiloxane (PDMS-OH).[36] Recent literature describes the linear segment as being either a polymerized siloxane or polyurethane in Remmers elastified ethyl silicate.[37] [38] Various siloxane modifiers have been explored, for example, inserting alkyltrialkoxysilanes or dialkyldialkoxysilanes into tetra functional network for the "internal plastification" as described by Škrdlantová, et al.[39] The results of this modified ethyl silicate were compared against Remmers Funcosil KSE 500 E and did not demonstrate a greater bending strength increase. Multiple sources confirm the favorable qualities of an elastified ethyl silicate. [40] Nonetheless, it is still needs to be tested for its consolidation effect on the specific stone(s) under study particularly considering the recommendation of the manufacturer when clays are present in the stone.[41] [42]

Another way to solve the issue of cracking is to increase the pore volume through the addition of small metal oxide particles to the consolidant, known as a particle modified consolidant (PMC).[43] Colloidal particles dispersed within the silicate-based

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[36] Salazar-Hernández, C., Alquiza, M. J. P., Salgado, P. and Cervantes, J. "TEOS–colloidal silica–PDMS-OH hybrid formulation used for stone consolidation." *Applied Organometallic Chemistry, v.24*. 2010, 481–488.

[37] Ferron, Amila and Frank G. Matero. "A comparative study of ethyl-silicate-based consolidants on earthen finishes." *Journal of the American Institute for Conservation, v.50, n.1.* Eds. M. Derrick and P.Whitmore. Washington, DC: AIC, 2011. 49-72.

[38] Wendler, E. Ibid

[39] Skrdlantova, M., P. Kotlik, B. Dykova. "Modification of stone consolidants baed on organosilicone compounds." *10th International Congress on Deterioration and Conservation of Stone.* Stockholm:ICOMOS, 2004.

[40] Müller, Urs and Riedl Martin. "Volcanic tuff from Ettringen, Germany and its interaction with agents used for stone conservation." *11th International Congress on Deterioration and Conservation of Stone.* Ed J. Lukaszewicz and P. Niemcewicz. Tourun:Nicolaus Copernicus University Press, 2008. 915-924.

[41] Remmers, KSE 300 E Technical Information Sheet.

[42] Studies that have shown improvement with treatment on strength or hardness and less to no cracking of consolidant in: Kim, Eun Kyung, Jongok Won, Jeong-Jim Kim, Yong Soo Kang, and Sa Dug Kim. "TEOS/GPTMS/Silica Nanoparticle Solutions for Conservation of Korean Heritage Stones." *11th International Congress on Deterioration and Conservation of Stone*. Ed J. Lukaszewicz and P. Niemcewicz. Tourun:Nicolaus Copernicus University Press, 2008. 915-924.

[43] Aggelakopoulou, Eleni; Charles, Pamela; Acerra, Matilde E.; Garcia, Ana I.; Flatt, Robert J.; and Scherer,

consolidant increase pore volume by creating a pore network upon curing that is based on the size and quantity of the dispersed particles.[44] This has been demonstrated as effective in reducing cracking whereas an elastified consolidant is designed to increase the elastic modulus of the gel, PMC's seek to address the action of capillary force on a gel. This issue will not be discussed as it is beyond the scope of this study.[45] [46]

George W. "Rheology optimization of particle modified consolidants." *Materials Issues in Art and Archaelogy, VI.* Eds. P. Vandiver, P., Goodway, M., and Mass, J. Boston: Materials Research Society, 2002. 15-20.

[44] Escalante, Matthew R., John Valenza, and George Wheeler. "Compatible consolidants from particle-modified gels." *9th International Congress on Deterioration and Conservation of Stone.* Ed. Vasco Fassina. Amsterdam: Elsevier Science, 2000. 459-465.

[45] Kissane, Paul and Sara Pavia. "Application of modified teraethoxysilanes to Irish sandstone in laboratory trials." *Proceedings of the International Symposium: Stone consolidation in cultural heritage research and practice*. Eds. José Delgado Rodrigues and João Manuel Mimoso. Lisbon:LNEC, 2008. 319-328.

[46] Studies that have shown improvement with treatment on strength or hardness and less to no cracking of consolidant in:

Kim, Eun Kyung, Jongok Won, Jeong-Jim Kim, Yong Soo Kang, and Sa Dug Kim. "TEOS/GPTMS/Silica Nanoparticle Solutions for Conservation of Korean Heritage Stones." *11th International Congress on Deterioration and Conservation of Stone.* Ed J. Lukaszewicz and P. Niemcewicz. Tourun:Nicolaus Copernicus University Press, 2008. 915-924.

Chapter 4: Testing Methodology

4.1 Sample Preparation

Bulk samples of sandstone were provided by Durham University. It is assumed that the samples are representative of decayed stone that is typically removed from the exterior masonry walls at Durham Castle. These bulk samples were cut into cubes by Dan Lepore & Sons Company, located in Conshohocken, Pennsylvania. A KMY dual-head waterjet at 90,000 psi, or 620,532 kPa, was used to cut the stone into cubes of approximately 5x5x5cm and coupons of approximately 5x5x2cm. Eight of the nine cubic samples had cut surfaces, while the ninth one contained a weathered surface on one face, unavoidable given the limited stone supply. All coupons had cut faces. Samples were labeled on the top face using an archival ink pen (see Figure 4.1). Cubes were prepared to test the wetting and drying behavior as well as the depth of penetration of the consolidant (Figure 4.2). The coupons were prepared for testing water vapor transmission (Figure 4.3 and 4.4).

In 2010, a representative stone sample with alveolar erosion was provided by Durham University (Figures 4.4 to 4.7) and this was also used for testing. This sample is referred to as bulk sample B henceforth in this thesis. Table 4.1 gives the identification code for all samples.

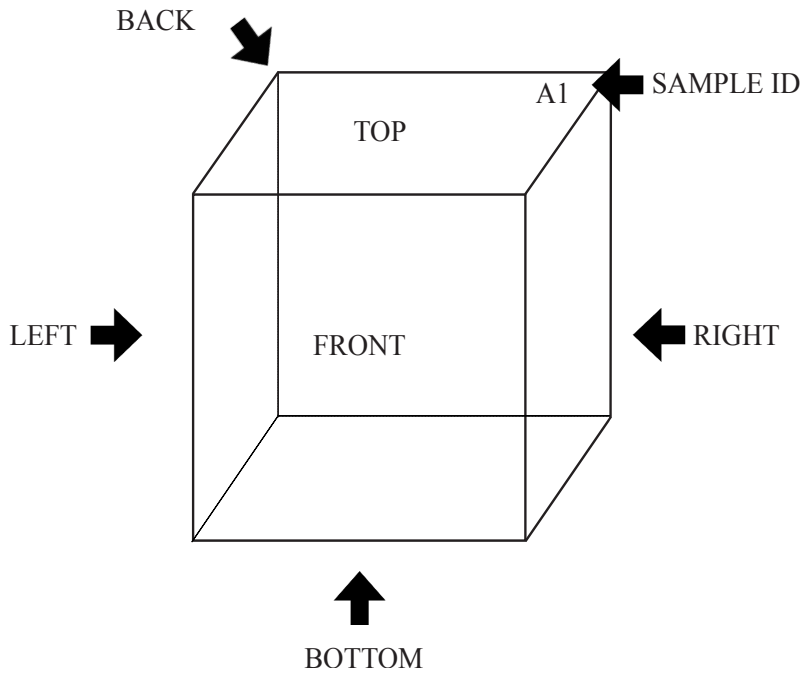

Figure 4.1 Diagram showing label system of the cubic samples.

Table 4.1 Sample identification by treatment.

Treatment	Sample ID: 5x5x5cm	Sample ID: 5x5x2 cm	Bulk Sample
Prosoco OH100	A.1 A.2 A.3	A.4 A.5 A.6	B_Prosoco
Remmers KSE 300 E	B.1 B.2 B.3	B.4 B.5 B.6	B_Remmers
Untreated	C.1 C.2 C.3	C.4 C.5 C.6	B_Control

*Although confusing, the bulk sample retained the preliminary identification of "B_x" because it was identified as such in Simple's thesis in 2010.

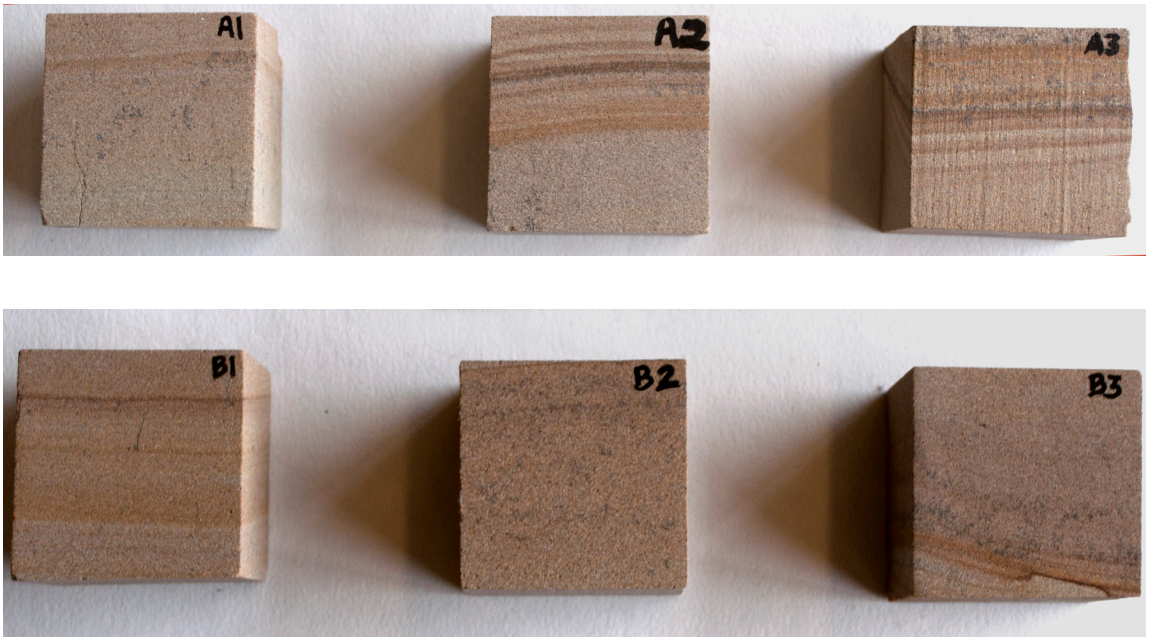

Figure 4.2 Cubic samples A1-B3 before treatment.

Figure 4.3 Coupon samples A4-C6 before treatment; oblique view to show relative thickness.

Figure 4.4 Coupon samples and the bottom of bulk sample B to show relative size and color.

Figure 4.5 Bulk sample B (front) showing cavity. Approximate overall dimensions are 10” x 8” 7.5”.

Figure 4.6 Bulk sample B with view of top (labeled B) and cavity profile.

Figure 4.7 Bulk sample B (bottom).

All samples were washed using deionized water and a soft nylon brush. After washing, they were placed in an oven at 40°C until constant weight was attained. They were placed in a sealed chamber with anhydrous calcium sulfate to cool overnight before treatments were applied. The samples were photographed using a Nikon D3100 DSLR camera and an 18-55mm Nikon lens. All images were taken by the author, unless otherwise specified. Photographs were edited in Adobe Photoshop Creative Suite 5.0 and color corrected using the Munsell x-rite color card.

Treatments were applied using a natural bristle two-inch width brush. For the bulk sample with the alveolar deterioration, the treatment of either Remmers KSE 300 E or Prosoco OH100 was applied in 2012 to portions of the weathered surface so that the depth of penetration by the consolidant could be determined. One portion was left untreated to serve as control (Figure 4.8).

Figure 4.8 Bulk sample B being treated with Prosoco OH100 (left) and Remmers KSE 300 E (right).

For the cut samples, the consolidants were applied with two even brush strokes per face. The cubes were treated on five of the six sides (Figures 4.9 and 4.10) and the coupons on the two largest faces (Figure 4.11). The edges of the coupons were not treated because the consolidant ran down them and most likely penetrated this surface to a certain degree. The Remmers KSE 300 E was absorbed far slower than the Prosoco OH100.

Samples were left overnight in a fume hood and then moved to a tented tray for curing. The samples cured for 52 days. During this time the temperature in the tented tray ranged between 63°F (17.2°C) and 75°F (23.8°C). The relative humidity fluctuated between12.6% and 61.7%, with an average of 33.8%.

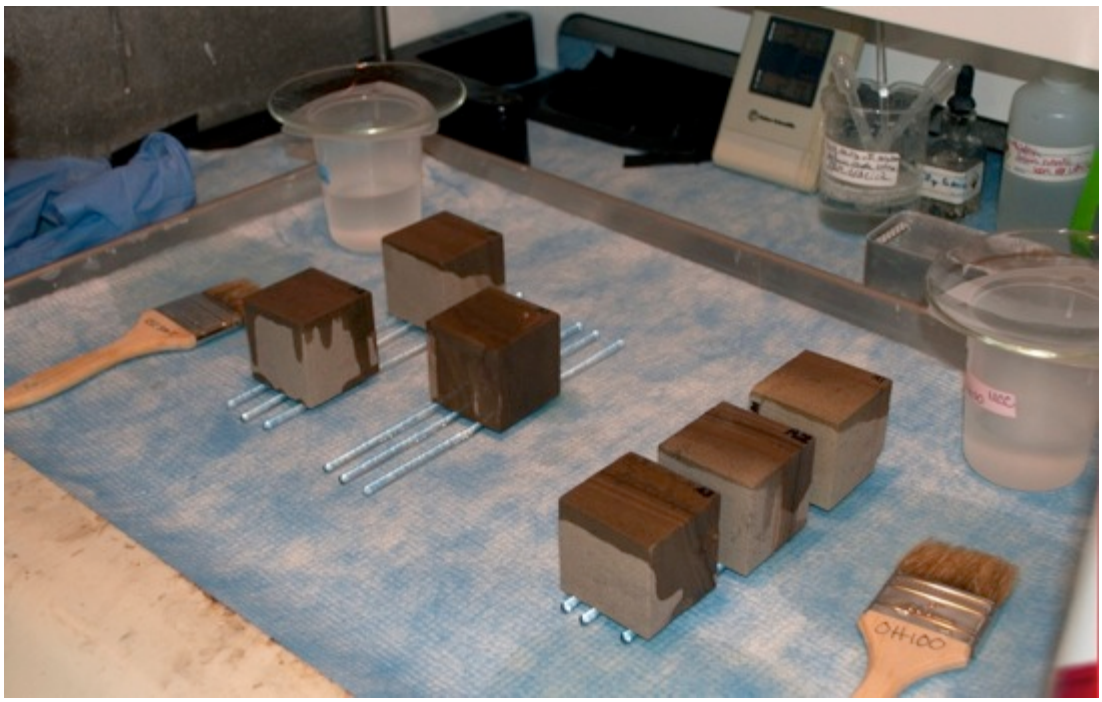

Figure 4.9 Samples being treated with Remmers KSE 300 E (left) and Prosoco OH100 (right).

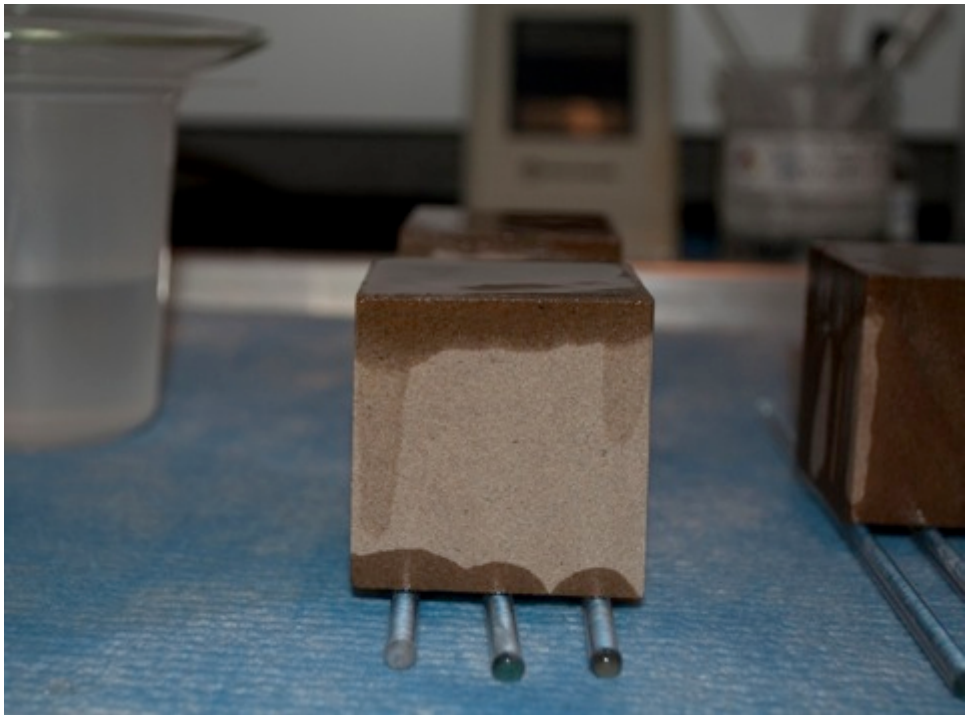

Figure 4.10 Close up of a sample being treated with Remmers KSE 300 E.

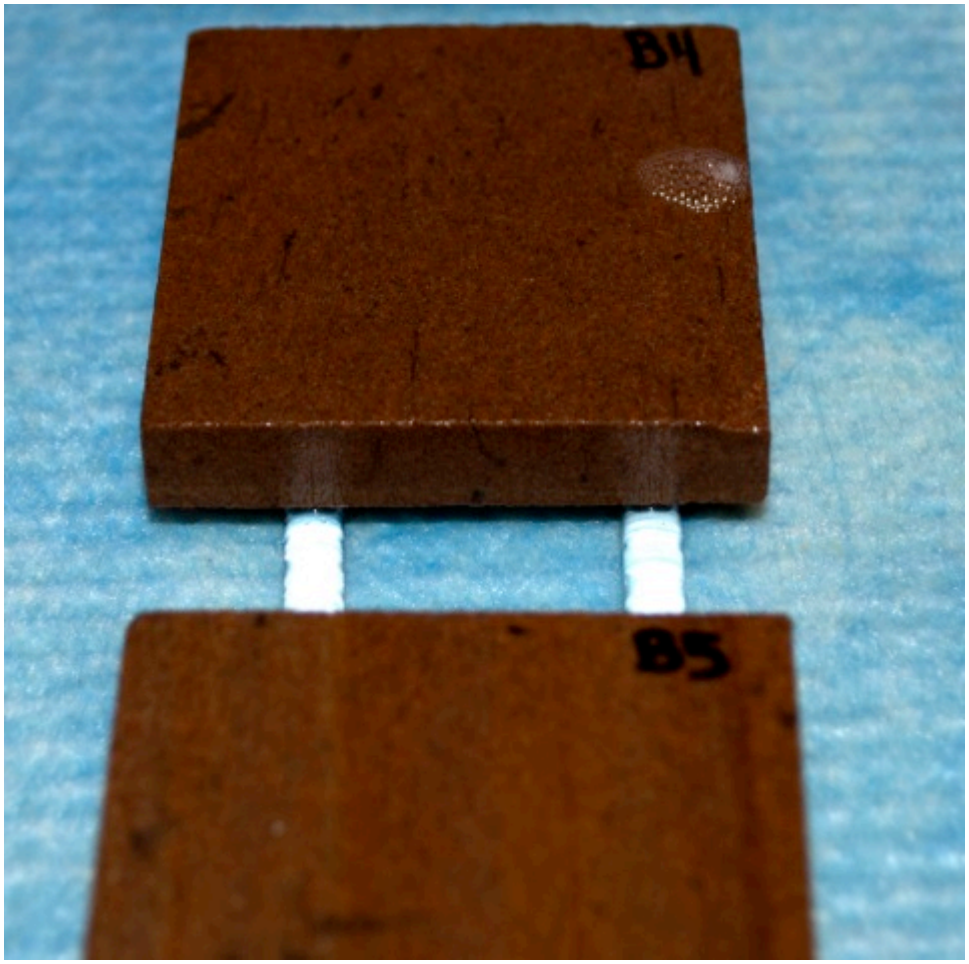

Figure 4.11 Coupons being treated with Remmers KSE 300 E.

4.2 Testing Methodologies to Evaluate Treatment Performance

The treated samples described in the previous section were subjected to six different evaluation techniques in order to observe the impacts of the selected treatments on the stone. These evaluation methods include: water absorption, drying behavior, water vapor transmission, color changes, scanning electron microscopy, and drill resistance. The outcome of this testing will help determine the best treatment.

The first three methods serve to evaluate the movement of water, liquid or in vapor state, through the stone. Since ethyl silicates are designed to restore inter-granular cohesion within a stone they can potentially alter both capillary absorption as well as the

water vapor permeability of the stone. This is important for several reasons, among which is the fact that the treatment is unlikely to be uniform when applied on site; some areas may be consolidated while other may remain untreated. And if there are difference in either capillarity or water vapor diffusion, then water may be retained longer in one area to another leading to differential damage such as could be induce by temperature gradients that may lead to localized damage through freeze-thaw.

It is essential to determine the depth to which a consolidant penetrates the stone to ensure that the deteriorated region of the stone has been fully treated. For the evaluation of the depth of penetration, there are several options ranging from non-destructive ultrasonic pulse velocity, to the minimally destructive resistance drill method, to a totally destructive method of three-point bending or compressive strength test. Given the limited amount of samples available, compressive strength and three-point bending tests were not considered for this study.

The methods used are based on accepted standards, however sometimes these have to be altered to accommodate the limitations of the equipment or samples size and shapes. The methods employed will be described in further detail in the following sections. For drill resistance, a fairly recent method, there is not a recognized standard. Nonetheless, there is significant literature on the subject, and as with any method, it requires practice by the conservator to become fully acquainted with the instrument.

4.3 Water Absorption and Drying Behavior

The wetting and drying behavior of a consolidated stone is fundamental for predicting how a treated stone will behave in an outdoor environment. At Durham, the

masonry walls are subjected to rain and snow and occasional freezing temperatures. Therefore if a consolidation treatment drastically alters the sandstone's ability to absorb water or retain it, entrapment of water within the masonry would likely result in damage.

For the purposes of this thesis, a capillary water absorption curve, capillary water absorption coefficient, and determination of the water capacity of the stone, as well as the drying curve and drying rate were determined using laboratory instructions prepared by Dr. A. E. Charola for University of Pennsylvania's Advanced Conservation Course in the Historic Preservation department. These instructions can be found in Appendix E and are based on ASTM C97-96, NORMAL 7/81, NORMAL 11/85 and NORMAL 29/88.

4.4 Water Vapor Transmission

It is necessary to examine the effects a consolidation treatment has on the permeability of the stone to water vapor. Permeability, as it relates to water vapor transmission, refers to the quantity of water vapor that passes through a material of a known thickness and surface area within a given amount of time and under specified temperature and humidity conditions.[47] Therefore, it is important to compare the rate of water vapor transmission through a treated and untreated material.

4.4.1 Testing Protocol

For the purpose of testing water vapor transmission the wet cup method in ASTM E-96 was primarily followed with some alterations to accommodate sample size and geometry. The wet cup method is based on the principle that water vapor will move from areas of higher vapor concentration (or relative humidity) to areas of lower relative

[47] ASTM E96-00 *Standard Test Methods for Water Vapor Transmission of Materials.*

humidity; in effect a vapor pressure difference encourages the movement of water vapor through the specimen. The sample is then weighed at specified intervals to determine the rate of water vapor movement through the sample.

For the "cup" of the test assembly, a commercial blown glass cubic vase was used. Excess glass was removed from the base of the vase using a wet saw in the University of Pennsylvania's Fabrication Laboratory. The removal of excess glass was necessary to reduce the vase's weight to values within the range of the scale available for use in this experiment. The vases have a 3 x 3 inch (7.62 x 7.62 cm) opening and an approximate height of 4 inches (10.16 cm). Acrylic sheets of 1/8 inch (0.3175 cm) were cut into squares of 3x3 inches (7.62 x 7.62 cm) using a laser cutter. A center rectangular portion of each acrylic square measuring was 5.10 x 5.14 inches (13.00 x 13.05 cm) was removed to accommodate the samples. The acrylic squares were then adhered to the glass base using a clear silicone sealant. Fifty milligrams of distilled water was poured into the assembly. Four small cotton balls were also placed within the assembly to help prevent condensation (Figure 4.12).[48]

[48] Pingarron Alvarez, Victoria. *Performance Analysis of Hydraulic Lime Grouts for Masonry Repair* (Master's Thesis). University of Pennsylvania, Philadelphia, PA, 2006.

Figure 4.12 Wet cup assembly.

Figure 4.13 Applying electrical tape to the edges of specimens.

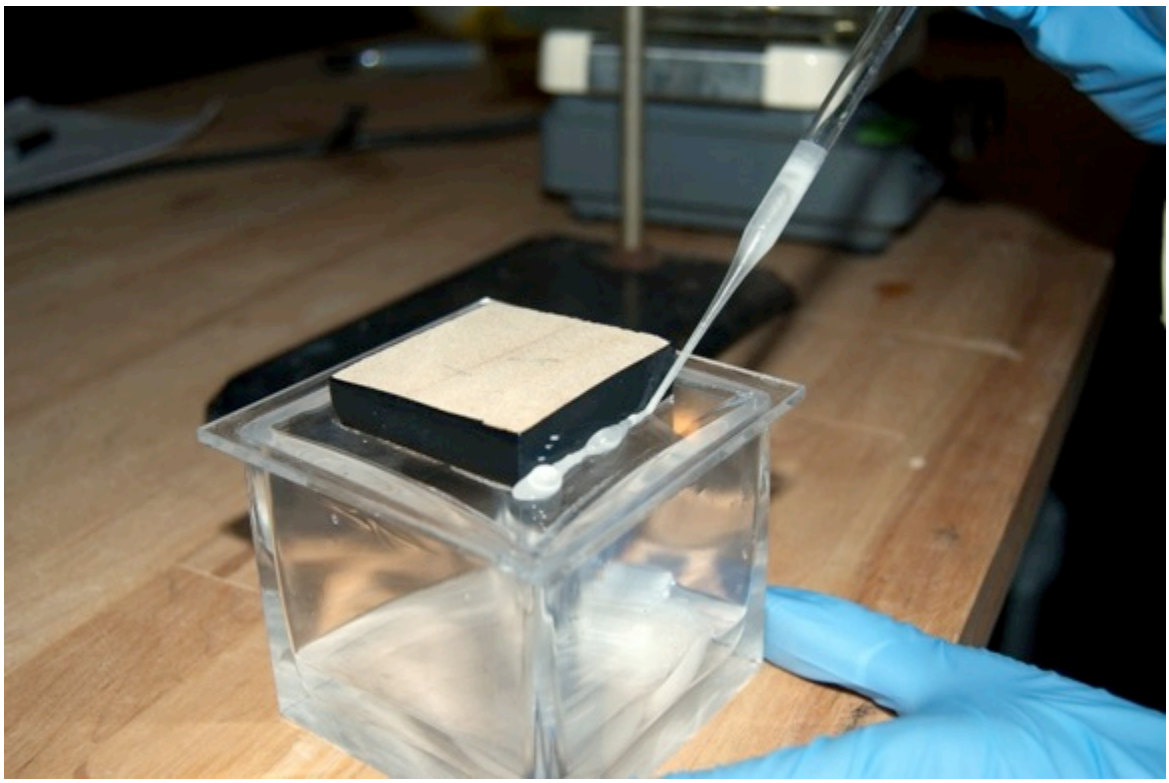

Figure 4.14 Applying heated paraffin wax using a pipette.

The samples were dried in an oven at 60° C until constant weight was achieved. The edges of each sample were then wrapped with black vinyl chloride plastic electrical insulating tape three times and placed in the opening of the assembly (Figure 4.13). Melted paraffin wax was applied using a disposable pipette to secure the sample into the assembly and prevent water vapor from passing between the edges of the sample and the assembly opening (Figure 4.14). The assemblies were placed in a sealed chamber along with a shallow tray of approximately 800 grams of anhydrous calcium sulfate to maintain a relative humidity of 50% ± 2% within the chamber. The temperature and humidity were monitored using a Hobo data logger (see Appendix C).

In order to ensure the accuracy of the data logger, the data logger was placed in a sealed testing chamber with a saturated solution of calcium chloride for 48 hours. At 20°

C, a saturated solution of calcium chloride maintains the relative humidity at 31%. This exercise confirmed the accuracy and precision of the data logger.

Each assembly was weighed at fifteen-minute intervals for the first hour and then approximately every twenty hours thereafter until a sufficient number of points was obtained. Since the temperature and relative humidity in the laboratory could not be controlled, every time the chamber was opened, fluctuations in the relative humidity of the chamber could be observed as a consequence. Therefore, the number of times and duration for which the chamber had to be opened was limited to a minimum to diminish this problem.[49]

4.5 Change in Color and Surface Texture

The goal of a conservation treatment, such as consolidation, is to extend the lifetime of an object, without introducing new types of deterioration. However, visual changes are an important a consideration for treatment for architectural elements in exterior masonry. The most important ones are changes in color and surface texture because these will affect the historical character and aesthetic qualities of the structure.

4.5.1 Methodology

Samples were color-matched using a Munsell Soil Color Book in natural light after the curing period of fifty-two days.[50] Because this stone is a sedimentary stone, the color differs by bed (different beds can contain grains of different colors). Color

[49] Chang, S. C. and Hutcheon, N. B., "Dependence of Water Vapour Permeability on Temperature and Humidity*". Transactions American Society of Heating and Air- Conditioning Engineers (ASHRAE),* Vol. 62, No. 1581. 1956, 437-449.
[50]Munsell Soil Color Charts. *Munsell Color*. New Windsor: GretagMacbeth, 2000.

matching was done to match the lightest, overall color of the stone and some granular inclusions. Striations of unique color inherent to the untreated stone were not color matched. The results were then compared between treated samples and untreated samples.

4.6 Scanning Electron Microscopy

Scanning electron microscopy (SEM) serves to examine the surface topography and texture of a material at far higher magnification than with an optical microscope. SEM uses a beam of electrons to energize the atoms within the sample. Some electrons will "bounce off" the surface, i.e., backscattered electrons, while others will interact with the sample releasing other electrons, i.e., secondary electrons. These are picked up by a detector and then displayed on a computer screen. To avoid electrical charging of the sample when electrons impinge upon it, non-conductive substances must be coated with a conductive material, for example, carbon. Only a small sample is required for examination, making this analysis possible even when sample specimens are limited.

SEM is a powerful tool because it typically can provide images of a specimen at a resolution between 1nm to 10nm with a large depth of focus.[51] It can be used to observe the grain shape and size, as well as the pore space between them. In the case of consolidated samples, the presence of the consolidant can be determined, and in particular how it coats the grains of the sandstone.[52]

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[51] Egerton, Ray F. *Physical Principles of Electron Microscopy an Introduction to TEM, SEM, and AEM*. New York:Springer, 2005.
[52] Karas, Natalie. *Evaluation of the 1993 Conservation Treatment of the San Jose Convento Column, San Antonio Missions Nataional Historic Park, San Antonio, Texas*. (Masters Thesis). The University of Pennsylvania: Philadelphia, PA, 2011.

4.6.1 Sample Preparation

Scanning electron microscopy (SEM) was performed on four stone samples at the Winterthur Museum Scientific Research and Analysis Laboratory by Catherine Matsen. The stone samples, approximately 0.5-1.0 mm^2 in diameter, were mounted to a carbon stub with double-sided carbon tape adhesive with the surface to be analyzed facing up. The stone samples were carbon coated with the SPI-Module Carbon Coater (Figure 4.15). Samples were examined using the Topcon ABT-60 scanning electron microscope at an accelerating voltage of 11kV, stage height of 22mm, and sample tilt of 20°. Secondary electron images (SEI) were captured with Bruker Esprit 1.8 software. The samples examined were taken from the large stone, identified as sample B in the 2010 thesis. This stone had been treated with Prosoco OH100 on one third on the eroded face and Remmers KSE 300 E on the other third. The remaining third of the stone was left untreated, as a control.

Of the four samples, one sample was taken from the untreated area that exhibited a small pit so that surface erosion could be analyzed. Another sample was taken from an untreated area and the broken edge examined, so as to contrast its imagery with the surface. Lastly, one sample was taken from each of the treated surfaces.

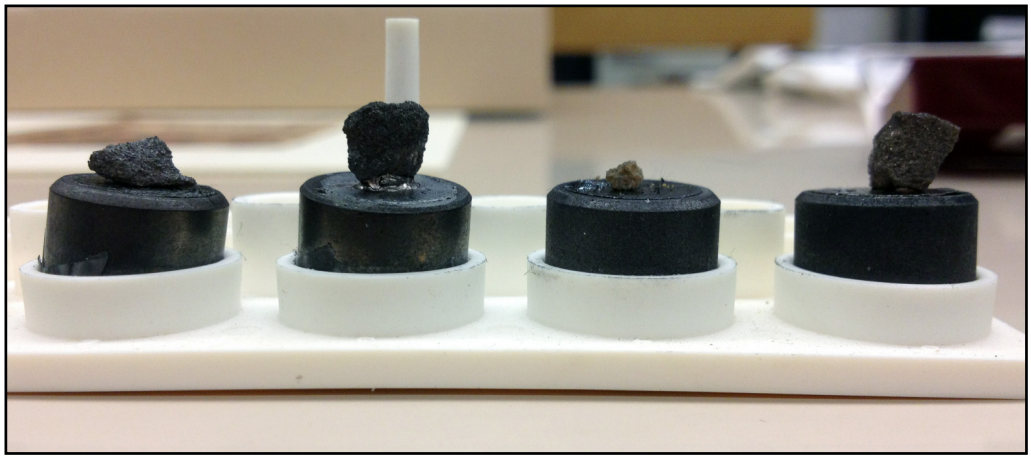

Figure 4.15 Carbon-coated samples prepared for SEM.

4.7 Resistance Drill Testing

It is essential to determine the depth to which a consolidant penetrates the stone. This is to ensure that the deteriorated region of the stone has been fully treated. To evaluate the depth of penetration, the minimally destructive method of drill resistance was used. The usefulness of a resistance drill goes beyond simply determining the depth of penetration; it also provides semi-quantitative information on the hardness of the stone at various depths, resulting in a strength profile curve that relates hardness of the stone to depth. The benefits of using a resistance drill are clear: a resistance drill is minimally destructive and provides quantifiable information on the depth of penetration and strength profile. Since this is a relatively new technique and it is the first time that it was used in the Conservation Architectural Laboratory, an overview of the technique is presented.

4.7.1 Overview of the Drill Resistance Method

Ferreira Pinto and Rodrigues Delgado (2008) cite drilling resistance as suitable to assess strength changes resulting from consolidation treatments. Additionally, the International RILEM Workshop *on On Site Control and Non-Destructive Evaluation of*

Masonry Structure (2001) concludes that portable drill resistance techniques are sensitive and reliable enough to be a "useful tool to verify the "cohesion profiles" of natural stones...to collect detailed information on their decay state and on the performance of conservative treatments applied on them". In fact, Tiano et al (2000) have proven the relationship between uniaxial compressive strength and drilling resistance.[53] And a linear relationship between drilling resistance and uniaxial compressive strength that relates to the Mohs hardness scale has been established by Pamplona et al. (2007).

Nonetheless, there are drawbacks to the use of the drill. First, some research has shown that in some cases consolidation treatments are not detectable with a DRMS drill.[54] And recent research has confirmed that the method is not suitable for analyzing some consolidation treatments because of the limitations of a carbide-tipped drill when the maximum thrust of the drill is set at 100N. In these cases, an abrasive tip-coated coring bit provides an alternative.[55]

Furthermore, the accuracy and precision of the data obtained are subject to problems of drill bit wear, dust accumulation within the drill hole, user error. To account for drill bit wear, one can either replace the drill bit with each successive hole or correct the data through calculations. An equation for heterogeneous materials calculates the wear rate. It is expressed as:

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[54] Croveri, Paola, Luigi Dei, Rodorico Giorgi, and Barbara Salvadori. *Consolidation of globigerina limestone (Malta) by means of inorganic treatments: preliminary results.* Proceedings of the 10th International Congress on Deterioration and Conservation of Stone, vol 1. 2004, 463-470.
[55] Mimoso, Joao-Manuel and Doria Rodrigues Costa. *A new technique for using the DRMS in hard materials. Application to the study of consolidation action*. ICVBC Online Publications. Web March 2012. <http://www.icvbc.cnr.it/drilling/publications/consDRMS_findc.pdf>.
[10] Rodrigues, J. Delgado and D. Costa. "A new method for data correction in drill resistance tests for the effect of drill bit wear". *International Journal for Restoration, v.10, no3*. 2004, 1-18.

"$Fc_i = [(Fm_i\ m\ r) / d_i + |x|]\ |x| + y$

Where:

Fc_i = corrected resistance at point i (N)

Fm_i = measure resistance at point i

d_i = total length drilled with a particular drill bit up to point i

x, y = coordinates of the common intersection point"[56]

The accumulation of dust leads to added resistance that can affect the precision and accuracy of the data results, resulting in an observed increase of force as the depth increases. Some experimental research has suggested the use of compressed air or vacuum to remove dust and improve results.[57] The use of core bits in combination with pressurized air has also been suggested. Ferreira Pinto et al. demonstrate the application techniques of dust suction and the use of a guide hole on drilling profile results. The use of a guide hole reduces the force (N) required, and increases the reliability and precision.[58]

Even though the drilling resistance method has gained popularity for the reasons mentioned above, it is still a relatively new technique and therefore data and comparative data for many stones is still limited to that obtained from compressive strength tests. For argillaceous sandstone and that suffering alveolar erosion, data is limited. It should be noted that there are multiple drill bit diameters available on the market and the hardness

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[57]Mimoso, Joao-Manuel and Doria Rodrigues Costa. *A new technique for using the DRMS in hard materials. Application to the study of consolidation action*. ICVBC Online Publications. Web. March 2012. <http://www.icvbc.cnr.it/drilling/publications/consDRMS_findc.pdf>.

[12]Ferreira Pinto, Ana Paula, Jose Degado Rodrigues, Susanna Bracci, Barbara Sacchi. "The action of APTES as coupling agent of ethylsilicate for limestone and marble consolidation". *Proceedings of International Sympostion Stone Consolidation in Cultural Heritage Research and Practice.* LNEC:Lisbon, 2008. 71-79.

[13]Pamplona, Marisa, Mathias Kocher, Rolf Snethlage, and Luís Aires Barros. "Drilling resistance: overview and outlook", October 2007. Web. <http://www.icvbc.cnr.it/drilling/publications/Paper%20Pamplona.pdf>.

of the stone often determines the size used. It is possible to compare data between tests of different bit diameters, using the following equation: [59]

$$DR_i = DR_m / l$$

Where:

DR_i = the diameter independent resistance value (N/mm)

DR_m = the measure resistance value (N)

l = length of the cutting tip (mm)

4.7.2 Equipment and Method

Currently there are two drilling machines on the market, one produced by SINT Technology and one by Geotron-Elektronik. The former measures the change in force (N) required to reach a certain depth in time, while the latter measures the time it takes to reach a depth, with force remaining constant.[60] For this study, the cordless drilling resistance measurement system (DRMS) sold by SINT was used to determine the depth of penetration using software provided by SINT. As mentioned, this measures the change in force (N) required to reach a certain depth in a given time.

To obtain strength profiles of both treated and untreated samples the software provided by the manufacturer was used in conjunction with the DRMS drill. One bulk sample (sample B) displaying alveolar erosion and consolidated (see Figure 4.8) was tested as were nine cubes, three per treatment. Holes were drilled at 900 RPM to a depth of 30mm and a penetration rate of 10mm/min using a Champion CSC4 1/8" (3mm) masonry percussion and carbide-tipped drill bit. For some drill holes on the bulk stone, a

depth of 30mm was unachievable in some areas because the samples were less than 30mm thick or because the force required to penetrate the stone exceeded 100 N. The force overload could happen as a result of the bit hitting a harder grain or a result of the bit tip dulling as it progresses through the stone

Cubes were easily secured to the drill using the plate attachment on the drill (see Figure 4.16). Securing the larger bulk sample B proved a more difficult task. The drill was too wide to fit into the cavity of the stone, so the stone had to first be cut using a masonry saw. The first cuts were made to create a roughly planar surface on the sample without eliminating the weathered and treated surface. The sample was then placed on a counter top and braced using sandbags. Sandbags were necessary because they conformed to the irregular shape of the stone while still providing the weight necessary to stabilize the specimen (Figure 4.17). However, this proved inadequate as it was still difficult to keep the sample stationary.

The bulk stone was then cut into small pieces, with two parallel sides so that it could fit between the attachment plates and be tested in the same manner that the cubic samples had. This still had its difficulties, as it was impossible to create a truly planar and parallel face on a weathered surface exhibiting alveolar erosion.

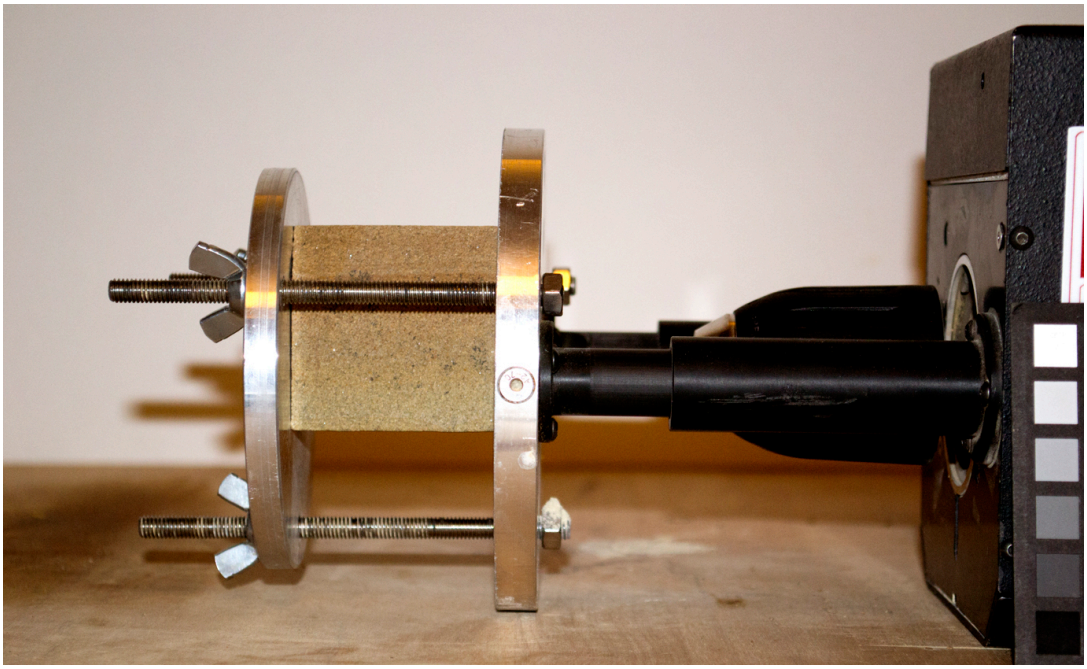

Figure 4.16 Image showing a cubic sample secured between two plates attached to the drill (right) for testing.

Figure 4.17 The author using the DRMS cordless on the bulk sample. Ultimately, the sample had to be cut into cubes in order to obtain strength profiles.

4.7.3 Practical Problems Encountered

Errors were introduced in several ways. First, although the Durham sandstone is weathered and weak, the quartz grains are extremely abrasive. This means that the drill bit showed wear and dulling after just one bore, as shown in Figure 4.18. While there are methods for correcting drill bit wear and abrasion,[61] these are better applied on less abrasive stones. Therefore, the best approach is to use a new drill bit for each hole drilled. This of course introduces the small error of differences between drill bits, as no two bits are exactly the same, not to mention the fact that the variety of drill bits available to researchers makes it difficult to compare data from study to study.

Another source of error is dust accumulation (see Figure 4.19). Even a small bore of 3mm diameter can produce a lot of dust that affects the performance of the bit. No practical solution was employed in this thesis, although corrections and possible alternatives were discussed in section 4.7.1. Still another source of error was operator error. The technique requires very steady hands and practice in doing the drilling in the selected spot. It also requires a planar surface and does not fit well within a cavity, such as one would find on the Durham stone. Last but not least, the battery of the cordless drill failed before a duplicate set of drill holes could be made, as was originally planned.

[61] Delgado Rodrigues, J. and D. Costa. "A new method for data correction in drill resistance tests for the effect of drill bit wear". *International Journal for Restoration*, Vol.10, No. 3: 2004, 1-18. Web. <http://www.icvbc.cnr.it/drilling/publications/correction%20drilling%20data_verso%20journal.pdf>. Accessed February 2012.

Figure 4.18 Image showing the effect of drill bit wear on the ability of the bit to penetrate the stone. The drill holes are numbered sequentially and by the third hole, the drill bit barely penetrated the stone.

Figure 4.19 Dust from the stone has accumulated and compacted in the channels of the bit, hindering its ability to penetrate the sample to a sufficient depth.

Chapter 5 Test Results

5.1 Capillary Water Absorption

The average capillary water absorption curves for representative samples, control (C) and treated with Prosoco OH100 (A) and Remmers KSE 300 E (B) are shown in Figure 5.1.The complete set of curves is found in Appendix A and the capillary absorption coefficients obtained from them are presented in Table 5.1.

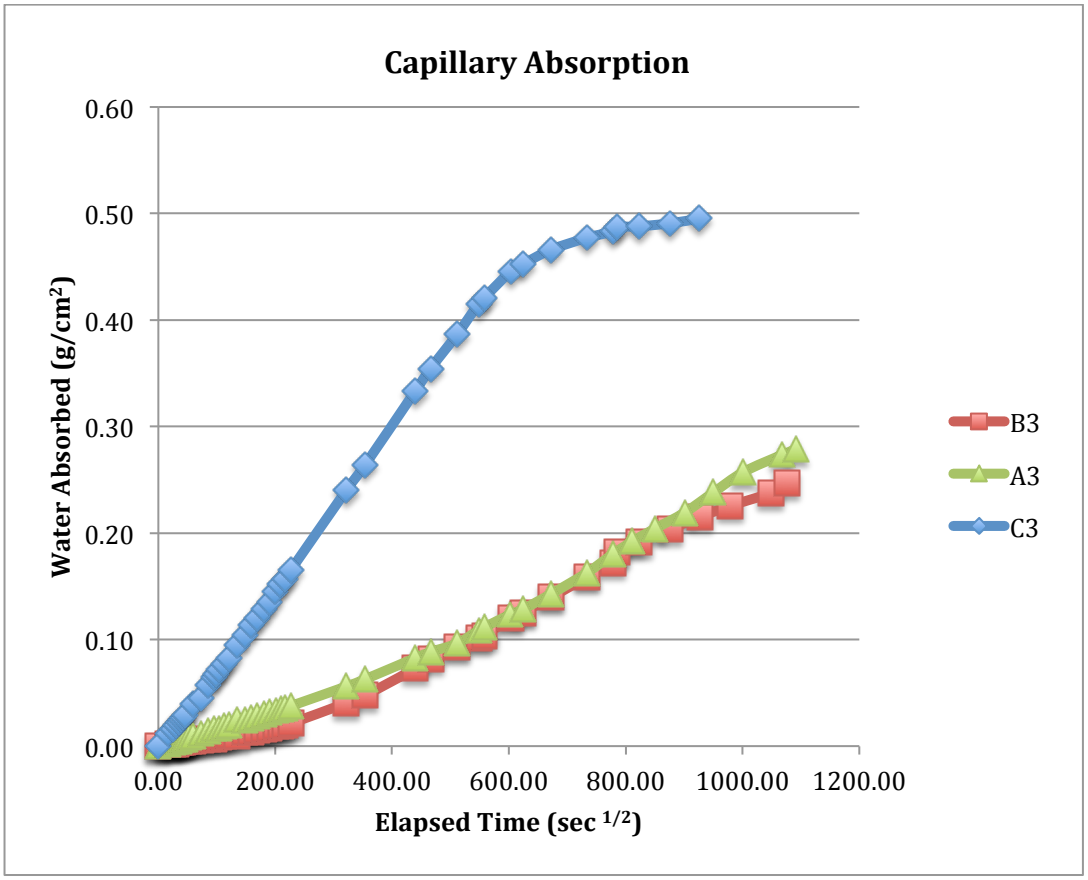

Figure 5.1 Average capillary absorption curves for the control (C), and the samples treated with Prosoco OH100 (A) and Remmers KSE 300 E (B).

It can be seen that the control sample reached an asymptotic absorption value at after about 10 days while the treated samples do not reach this value even after nearly two weeks. Furthermore, it can be seen that there is a significant difference in the capillary absorption rate. As expected the untreated samples absorbed water faster than the treated ones, while the elastified silicate ester (Remmers) treated samples (B) had the slowest absorption. This is because the Remmers product is slightly hydrophobic due to the siloxane segments introduced to provide flexibility to the resulting get. Probably because they were hydrophobic, these samples began to "perspire" a clear liquid about a day (approximately 28 hours) into testing (see Figure 5.2). The inside walls and lid of the container showed no signs of condensation, therefore it is speculated that this liquid was being released from the stone as water by-product of polymerization of the consolidant. A pH indicator paper was held to against the liquid on the stone surface and indicated that the liquid was slightly acid at pH 4.5. This phenomenon continued throughout the remainder of the capillary water absorption testing.

The capillary absorption coefficient for the Remmers samples corresponds to the small initial segment of the curve (up to around 14 hours, approx.200 $sec^{0.5}$), while that for the Prosoco samples could be obtained for the initial section up to 6 days. In the case of the control samples, it was reached within 4±1 day and the asymptotical value to which the amount of water absorbed tended was around 12.5 g, corresponding to 0.5 g/cm^2 as shown on the graph in Figure 5.1.

Table 5.1 Capillary absorption coefficients

Treatment	Sample ID	Capillary Absorption Coefficient ($g/cm^2sec^{0.5}$)	Correlation Factor
Prosoco OH100	**A1**	2.89E-04	0.992
	A2	2.37E-04	0.992
	A3	2.26E-04	0.993
Remmers KSE300E	**B1**	1.16E-04	0.997
	B2	0.93E-04	0.995
	B3	0.90E-04	0.994
Control	**C1**	6.48E-04	0.999
	C2	11.3E-04	0.999
	C3	7.65E-04	0.999

*Capillary absorption coefficients for the control and the treated samples. Note that because the treated samples, particularly the Remmers one, are slightly hydrophobic, the capillary absorption curves are modified and this is reflected in not reaching an asymptotic value and in the poor correlation factors corresponding to the calculated capillary absorption coefficient.

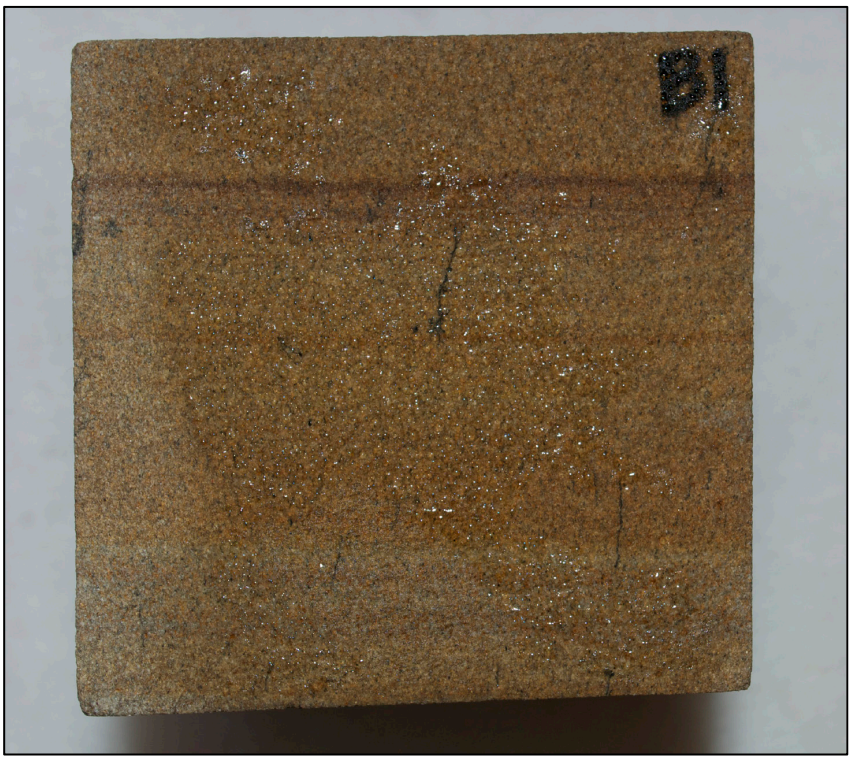

Figure 5.2 Sample treated with Remmers KSE 300 E showing the water droplets that formed on the stone surface during capillary absorption testing.

5.1.2 Total Immersion

After total immersion in water for 24 hours, the imbibition capacity, the apparent porosity and the open porosity could be calculated. These values are reported in Table 5.2.

Table 5.2 Imbibition capacity, apparent porosity and open porosity

Sample	Sample Code	Total Water Content (g)	Moisture Content (g/cm^3)	Imbibition Capacity	% Apparent Porosity	% Open Porosity
Prosoco	**A1**	9.3	0.074	0.031	3.13	7.44
	A2	8.2	0.066	0.026	2.57	6.56
	A3	8.1	0.065	0.026	2.63	6.48
Remmers	**B1**	7.2	0.058	0.024	2.39	5.76
	B2	8.2	0.066	0.026	2.63	6.56
	B3	7.5	0.060	0.024	2.41	6.00
Control	**C1**	12.2	0.098	0.039	3.87	9.76
	C2	13.2	0.106	0.045	4.50	10.56
	C3	12.8	0.090	0.041	4.14	8.98

* Data calculated from the total water content obtained after 24 hours immersion for the control and the treated samples.

The data show that the treated samples absorb less water than the control, the Prosoco-treated samples absorb about 65%, and the Remmers-treated samples, being slightly hydrophobic, only absorb 57% of the total amount taken up by the control. This is reflected in the corresponding imbibition capacity, the apparent porosity and the open porosity.

5.2 Drying Behavior

The drying curves obtained are shown in Figure 5.3. For the control samples the two that were not illustrated in Figure 5.1 are shown (showing that although these were

the higher and lower absorption curves, the drying curves are practically identical). Also illustrated is the Prosoco OH00 treated sample (A3) and the Remmers KSE 300 E treated sample (B3). All curves follow the same drying pattern and what is interesting is that the control samples retain more water than the treated ones. Of the treated samples, the Prosoco OH100 treated samples retained less water than those treated with Remmers KSE 300 E. Even after 15 days of drying, all the samples still retain water. Although the Remmers treated samples absorbed less water, the retained more water than the Prosoco treated samples, as reflected in the crossing of these two curves at around 100 hours (about 4 days).

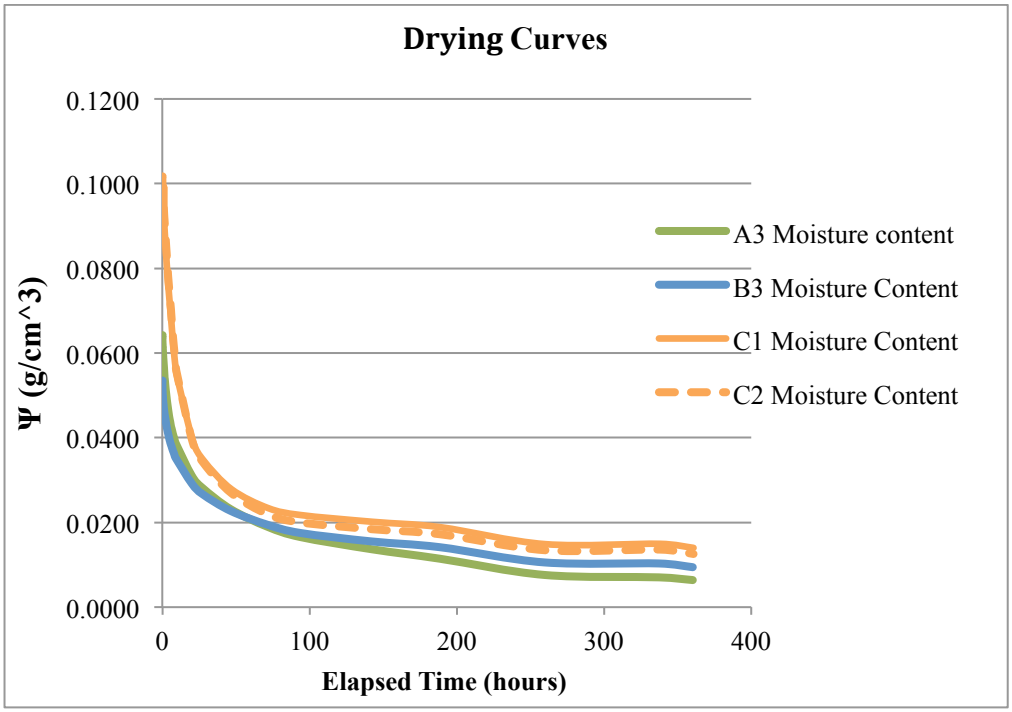

Figure 5.3 Drying curves for the control (C), the treated samples Prosoco OH100 (A) and Remmers KSE 300 E (B). Note that the control sample retains more moisture than the treated ones.

The drying rates varied less than the water absorption rates by treatment. The initial drying rate for the untreated samples is slightly faster rate than for the treated ones.

The initial and final drying rate for the shown samples are reported in Table 5.3 and includes the initial drying rates for all samples and their critical moisture content. The differences in the initial drying rates for the two sets of samples, the first run to determine the initial drying rate and the moisture content that was carried out in April 2012. The second run, on representative samples aimed to gain information of the time it took for them to equilibrate with the laboratory atmosphere, was carried out one month later, in May 2012. The initial drying rates are higher for the first run because the humidity in the laboratory was lower than for the second run. The initial drying rate, corresponding to the evaporation of moisture from the surface as long as there is a steady supply of liquid water reaching the surface, is mainly dependent on the ambient conditions where evaporation takes place.

Table 5.3 Initial and final drying rates, critical moisture content, and residual water content

Samples		**Initial Drying Rate ($g/cm^3.h$)**	**Correl. Factor**	**Critical Moisture Content (g/cm^3)**	**Final Drying Rate ($g/cm^3.h$)**	**Correl. Factor**	**Residual Moisture Content (g/cm^3)**
Prosoco OH100	**A1**	1.29E-02	0.996	0.062	-	-	-
	A2	1.10E-02	0.996	0.062	-	-	-
	A3	1.52E-02	0.996	0.064	-	-	-
	A3	*0.57E-02*	*0.993*	*0.061*	*10.7E-06*	*0.942*	*0.064*
Remmers KSE 300 E	**B1**	1.82E-02	0.994	0.053	-	-	-
	B2	1.29E-02	0.995	0.059	-	-	-
	B3	1.00E-02	0.990	0.059	-	-	-
	B3	*1.16E-02*	*0.993*	*0.051*	*2.73E-05*	*0.816*	*0.094*
Control	**C1**	1.11E-02	0.996	0.071	-	-	-
	C1	*0.50E-02*	*0.061*	0.061	*6.3E-06*	*0.620*	*0.014*
	C2	1.19E-02	0.995	0.064			
	C2	*0.50E-02*	*0.060*	0.060	*6.0E-06*	*0.564*	*0.013*
	C3	1.04E-02	0.995	0.056	-	-	-

*Data obtained after 15 days of drying at laboratory conditions. Data in italics and highlighted correspond to the second run which allowed to determine the final drying rate.

The data shows that after a fortnight, the treated samples retain between 6 to 9 times more moisture than the control samples, the higher value corresponding to the slightly hydrophobic Remmers treatment even though these samples had absorbed the least amount of water under total immersion (see Table 5.2).

5.3 Water Vapor Transmission

The plot of the weight loss of the selected samples over time is shown in Figure 5.3. A total of nine samples were tested (three samples per treatment), however one of each treatment is shown here (see Appendix C).

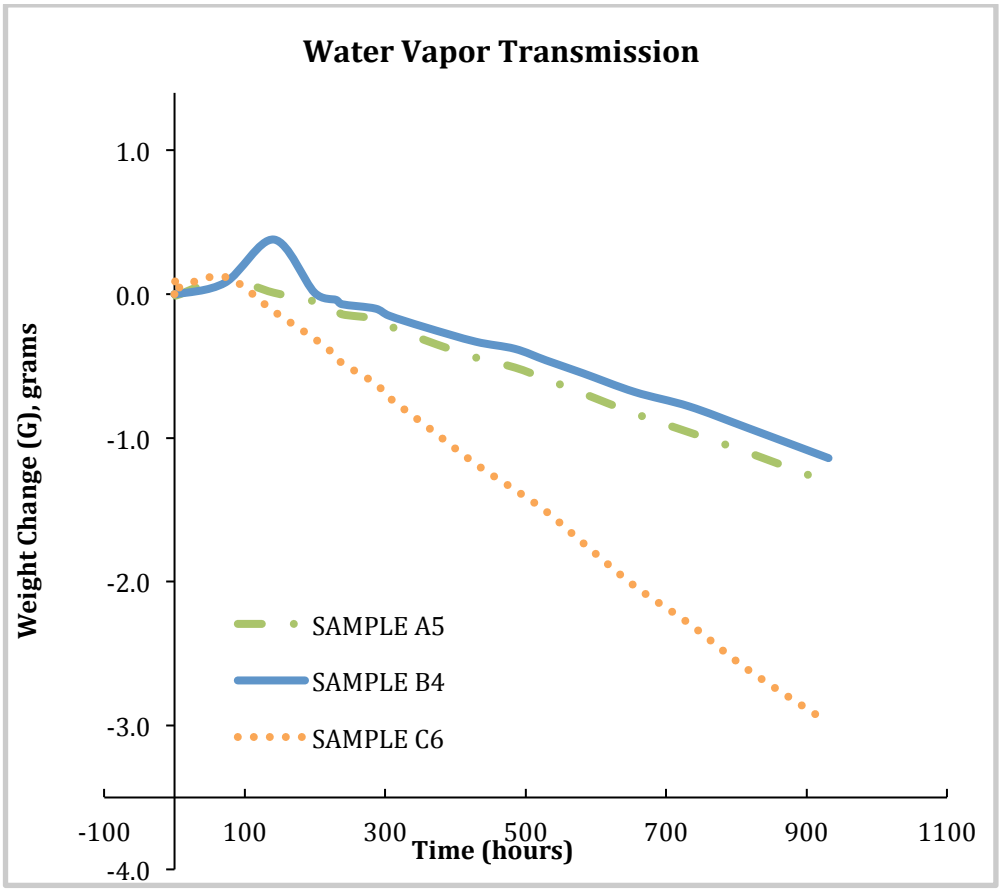

Figure 5.3 Plot of the weight changes of samples treated with Prosoco OH100 (A5), Remmers KSE 300 E (B4) and untreated control (C6).

The small weight increase at the beginning of graph reflects the stabilization of the samples when placed in the chamber for testing. Prior to the test, the samples had been stored in a desiccator chamber with a relative humidity of 21-25%. The relative humidity in the chamber for which the data was collected during the first twenty-four hours was at 50%. The stone absorbed water vapor from the air in the testing chamber until equilibrium was established within the stone's pores. At this point, water vapor began to move the anticipated direction, from within the testing apparatus (100% relative humidity) to the chamber (approximately 50% relative humidity).

All the data obtained in this test is summarized in Table 5.4. It presents the change in weight, water vapor transmission, and permeance of all samples tested. The water vapor transmission of the samples is calculated using the following formula, as recommended by ASTM E-96:

$$WVT = G/tA = (G/t)/A$$

Where:

WVT = rate of water vapor transmission ($g/h(m^2)$)
G = weight change (g)
T = time during which G occurred (hours)
G/t = slope of the straight line (g/h)
A = test area or surface area of sample (m^2)

Table 5.4 Water vapor transmission data

SAMPLE ID	A4	A5	A6	Avg A	B4	B5	B6	Avg B	C4	C5	C6	Avg C
WEIGHT CHANGE (g)	1.63	1.31	1.12	1.36	1.14	1.17	1.58	1.30	3.63	2.97	2.98	3.19
WVT ($g/h \cdot m^2$)	1.4 E-03	1.1 E-03	0.93 E-03	1.1 E-03	9.9 E-04	1.2 E-03	1.3 E-03	1.2 E-03	3.2 E-03	2.6 E-03	2.6 E-03	2.8 E-03
PERMEANCE ($g/Pa \cdot s \cdot m^2$)	2.4 E-07	2.0 E-07	1.6 E -07	2.0 E-07	1.7 E-07	2.0 E-07	2.3 E-07	2.0 E-07	5.5 E-07	4.5 E-07	4.6 E-07	4.9 E-07

***** Data for samples treated with Prosoco OH100 (A4-A6), Remmers KSE 300 E (B4-B6), and untreated (C4-C6). The column titled "Avg" is an average of all values for that set.

From the data in Table 5.4 it can be seen that both the Prosoco OH100 and Remmers KSE 300 E significantly reduced (nearly by half) both the water vapor transmission and the permeance of the stone, however, there is little difference between then as the values obtained are very close.

5.4. Observed Color Changes

The Prosoco OH100 most greatly altered the surface appearance of the weathered stone. After approximately 8 weeks of cure time, sample B, treated with Prosoco OH100 took on a different texture, almost play-dough-like and was a significant shade darker than the original stone (see Figure 5.4 and 5.5). The Remmers KSE 300 E did not change the texture and only the color was slightly darker. The untreated area of the bulk sample B matched 10YR 8/1 with granular inclusions of 5YR 6/5. The Prosoco OH100 altered the surface color to match Munsell 10YR 7/2 and the Remmers KSE 300 E treated area remained a closer Munsell color match to the original as it was 10YR 8/1 in some areas and 10YR 7/3 in others.

For the case of the unweathered cube and coupon samples, the Prosoco OH100 treatments only slightly darkened the surface and the Remmers KSE 300 E treatment had almost no effect on the color of the stone (see Figure 5.6 to 5.8). The measured Munsell color values for the control and treated cube samples is given in Table 5.5 and for the coupons in table 5.6. The values presented are an average of the value and chroma from all of the samples for a particular treatment. All of the samples exhibited iron oxide banding of 7.5YR 4/3 and inclusions of GLEY1 3/N.

There are cited examples of darkening of color with the application of OH100, for example, Ohio Massillon sandstone. In the case of the Ohio Massillon sandstone, yellow iron oxides were responsible for the darkening.[62] Other literature describes plain ethyl silicates as creating a "wet look" on sandstones.[63] Darkening occurs as a result of an increased reflection from the surface as the grains are coated by the consolidant.

Table 5.5 Munsell color values for unweathered and treated samples (cubes)

Treatment	Sample Identification	Color range after 16 weeks	Average color
Prosoco OH100	A1, A2, A3	10YR 5/2 – 10YR 6/3	10YR 5.5/2.5
Remmers KSE 300E	B1, B2, B3	10YR 6/2 – 10YR 7/2	10YR 6.5/2
Untreated (control)	C1, C2, C3	10YR 7/2	10YR 7/2

[62] Wheeler, George. *Alkoxysilanes and the Consolidation of Stone*. Getty Publications: Los Angeles, 2005.
[63] Cnudde, V., P. Dubruel, K. De Winne, I. De Wite, B. Masschaele, P. Jacobs, and E. Schacht. "Conservation products inside building stones". Dissertation. University of Ghent. Web. <http://users.ugent.be/~vecnudde/PHD/appendix/Publications/Cnudde%20et%20al%20cons%20prod%20Eng%20Geol.pdf.>.

Table 5.6 Munsell color values for unweathered and treated samples (coupons)

Treatment	Sample Identification	Color range after 17 weeks	Average Color
Prosoco OH100	A4, A5, A6	10YR 6/4	10YR 5.5/2.5
Remmers KSE 300E	B4, B5, B6	10YR 6/2 – 10YR 7/2	10YR 6.5/2
Untreated (control)	C4, C5, C6	10YR 7/2	10YR 7/2

Figure 5.4 Sample "B" after approximately eight weeks of curing. The entire area on the left (labeled A) was treated with Prosoco OH100. The peninsula-shaped outline in the middle (C), was left untreated, and the entire area on the right (B), was treated with Remmers KSE 300 E. Note that a portion of the Prosoco treated side (in the foreground) is lighter than the rest; this is actually a broken edge that occurred after curing and is not

indicative of a treated surface.

Figure 5.5 Enlarged image of the portion of sample "B" treated with Prosoco OH100. There is a noticeable color change between freshly broken stone (right) and the treated surface (left).

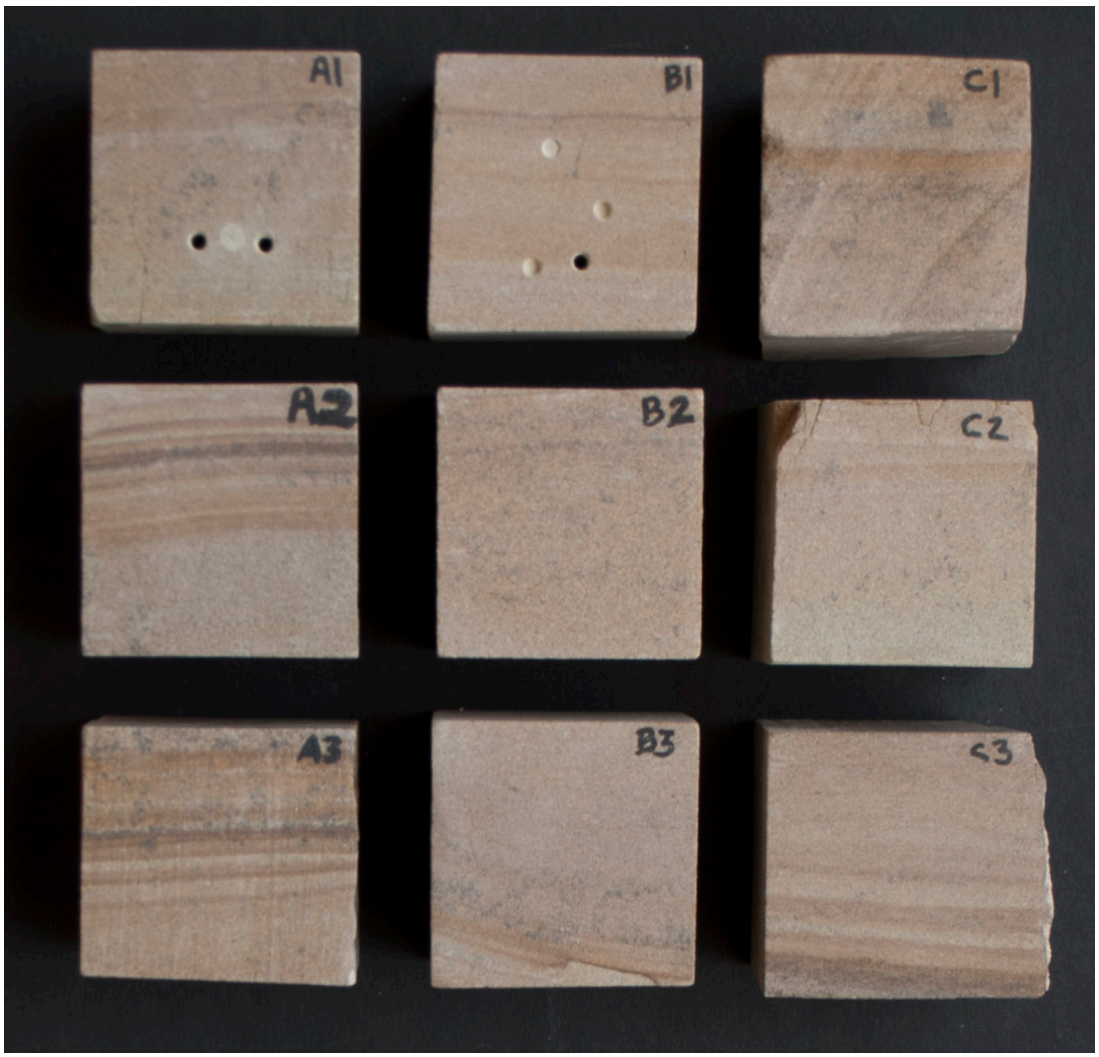

Figure 5.6 Cubic samples A1-A3, B1-B3, and C1-C3 after approximately 16 weeks of application of treatments.

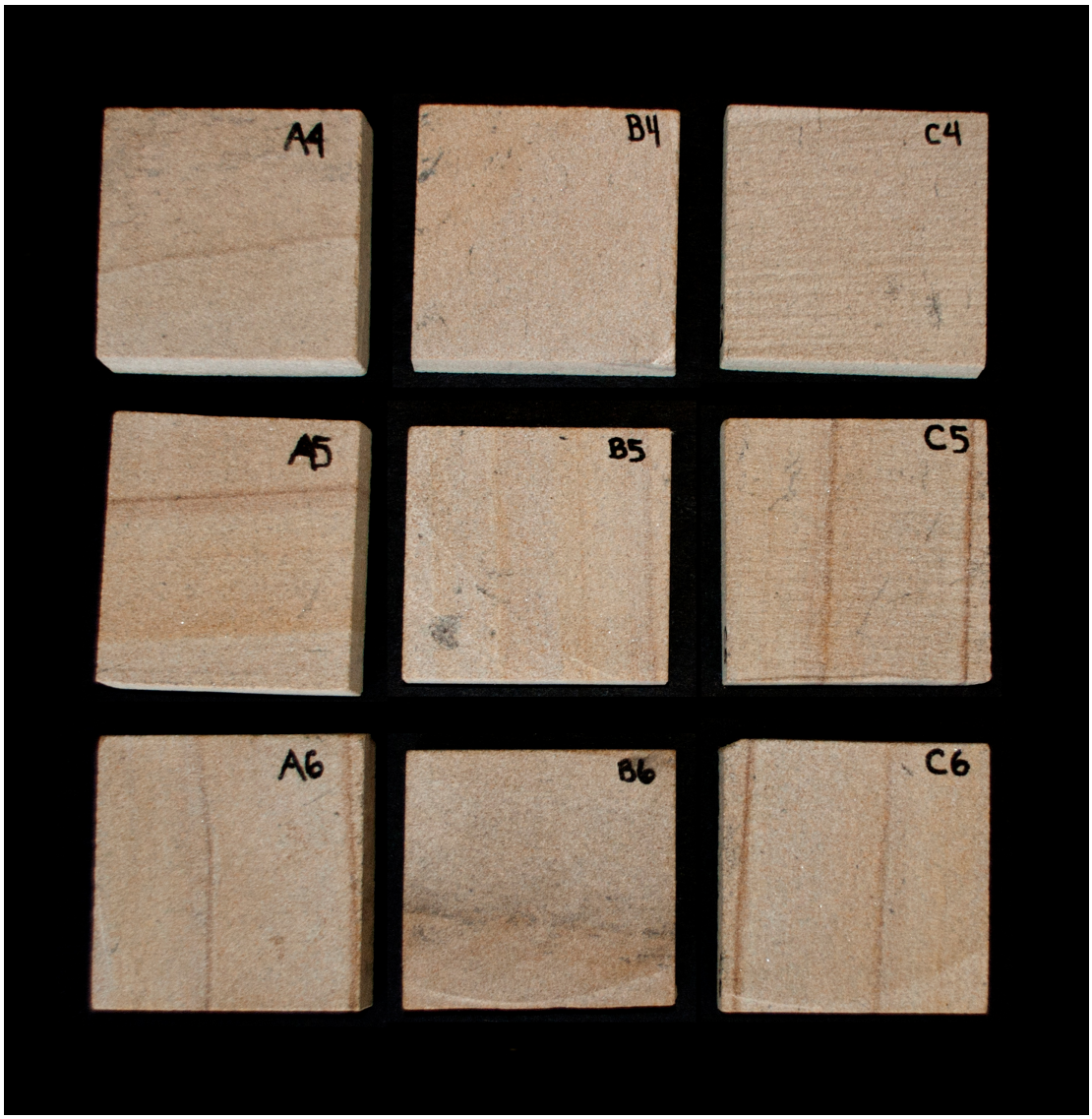

Figure 5.7 Coupon samples before treatment. A4-A6 are treated with Prosoco OH100, B4-B6 with Remmers KSE 300 E and C4-C6 are untreated.

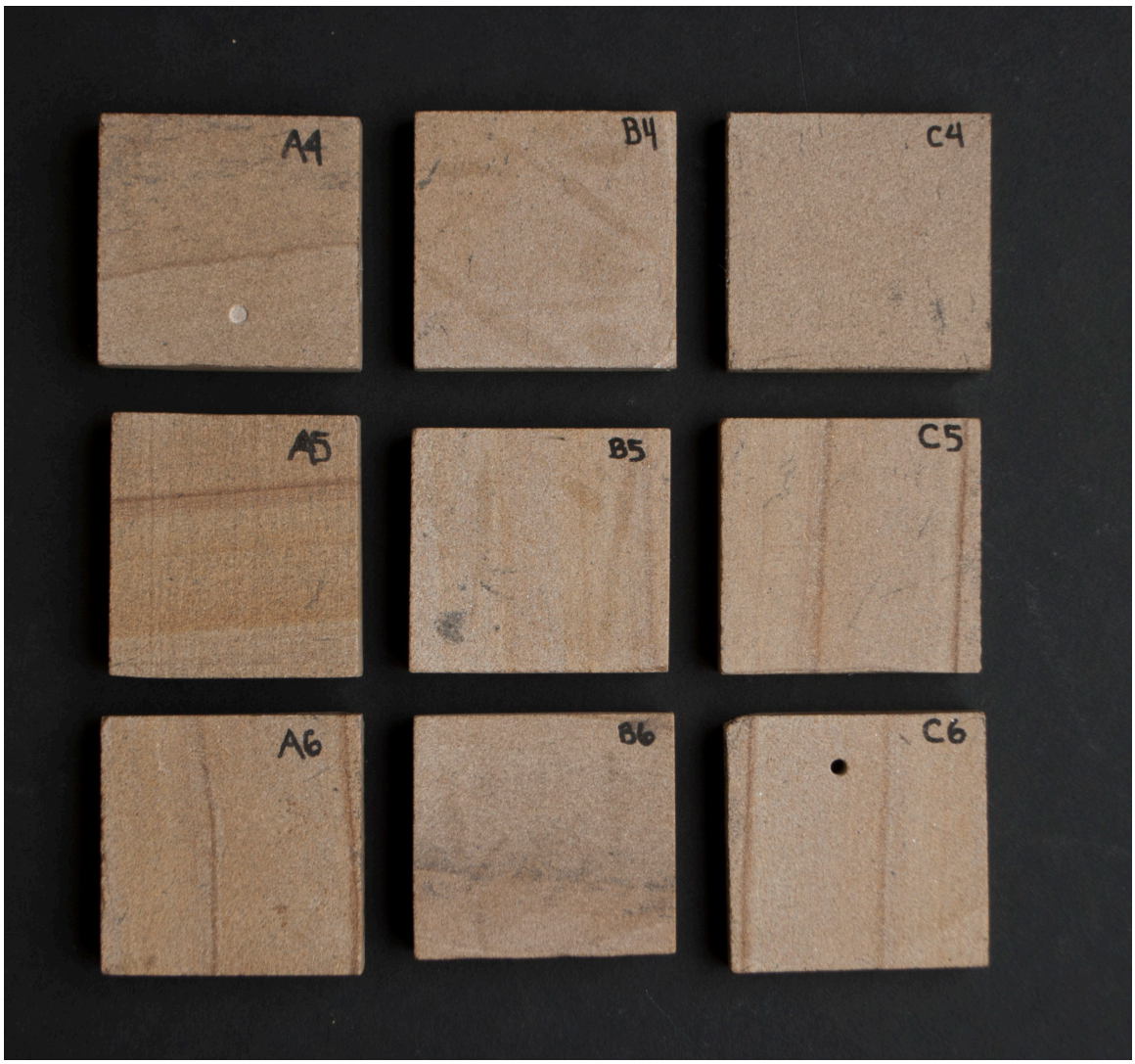

Figure 5.8 Coupon samples after treatment. A4-A6 are treated with Prosoco OH100, B4-B6 with Remmers KSE 300 E and C4-C6 are untreated. Samples B4-B6 have staining that mimics the glass rods on which the samples were placed during treatment and is probably a result of insufficient blanching of the surface with Naptha after application of the treatment.

5.5 Scanning Electron Microscopy

Scanning electron microscopy confirmed the presence of clays and feldspars as identified by XRD.[64] SEM photomicrographs of the weathered surface of a control (untreated) sample were taken from both inside a pit area and an edge fracture of the bulk sample B. Figure 5.9 to 5.11 correspond to the pit area, while Figures 5.12 and 5.13 correspond to the fractured edge.

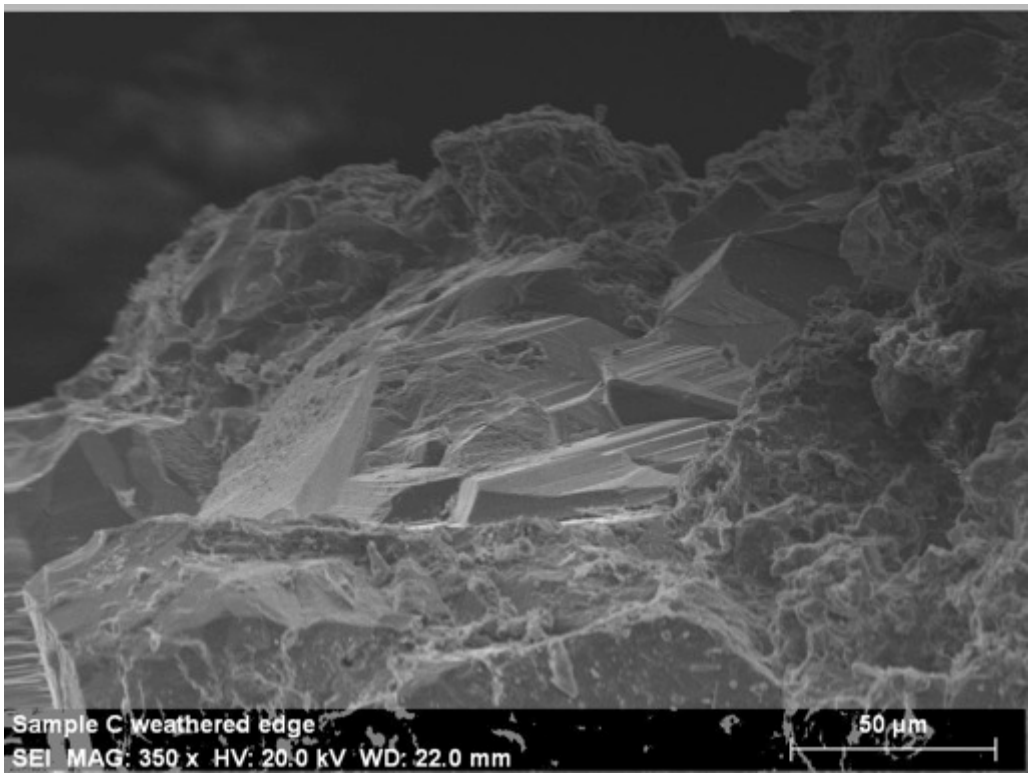

Figure 5.9 Secondary electron photomicrograph showing the general appearance of the weathered surface in the pit area of the control (untreated) sample C (350x). A large feldspar crystal is visible in the center, and beyond it in the upper left, is a quartz grain exhibiting conchoidal fractures. Another quartz grain is visible in the lower part of the figure below the feldspar.

[64] Simple, Tiffani. *Alveolar Erosion and its Conservation Recommendations for the Sandstone Masonry at Durham Castle* (Masters Thesis). University of Pennsylvania, Philadelphia, PA, 2010.

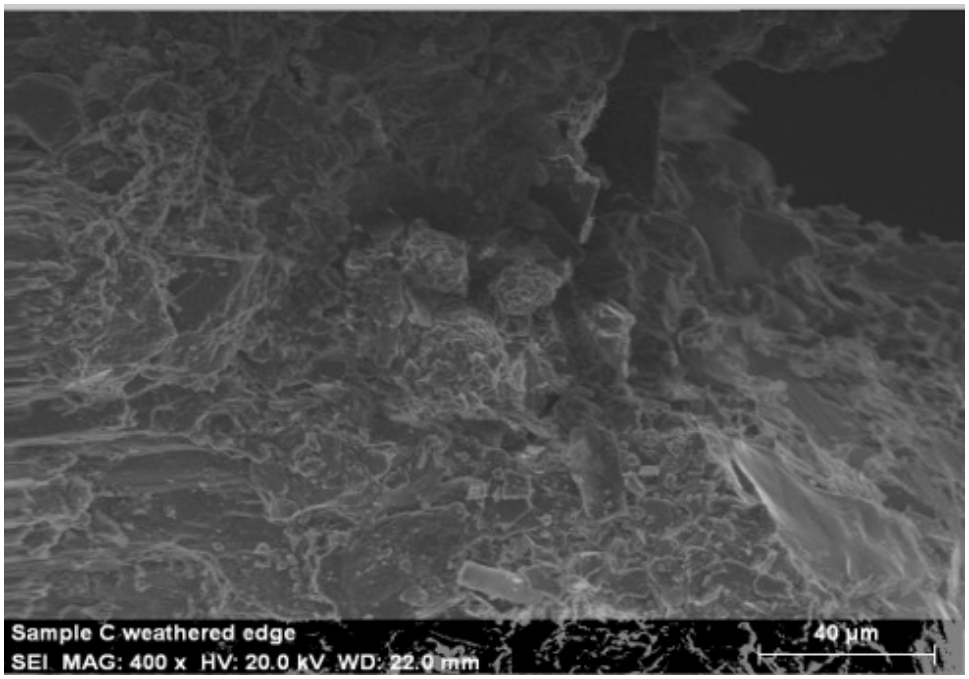

Figure 5.10 Another area of the same sample showing in the center what appears to be three clumps of gypsum crystals. On the lower right hand corner the conchoidal surface of a quartz grain (400x).

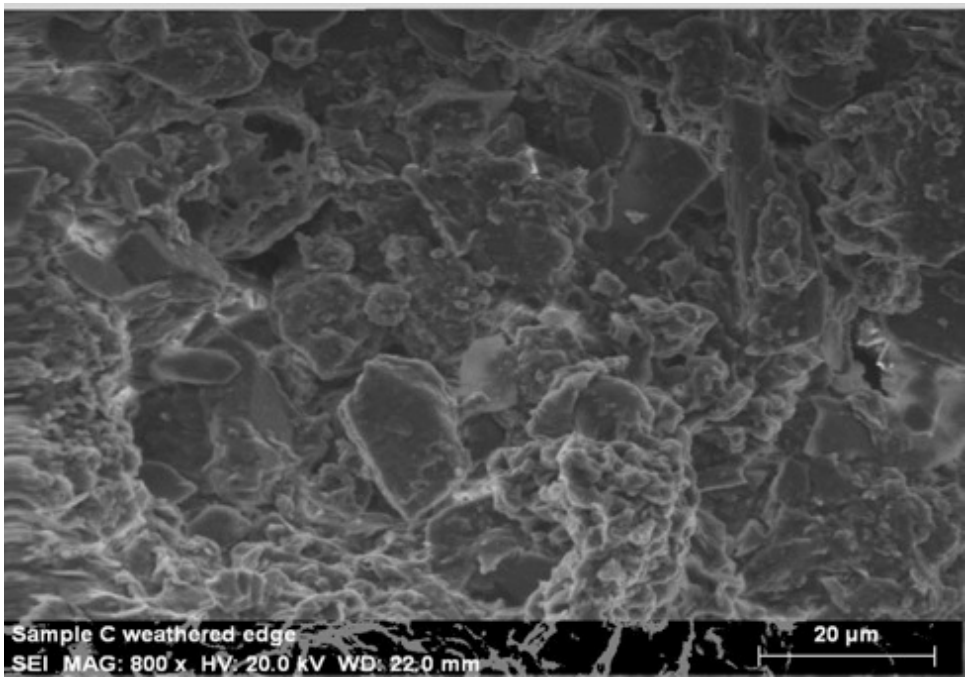

Figure 5.11 The same sample, at higher magnification (800x) shows the presence of a possible feldspar coated with clays on the top left corned. Note the relatively low porosity and fine grain size of many of the particles.

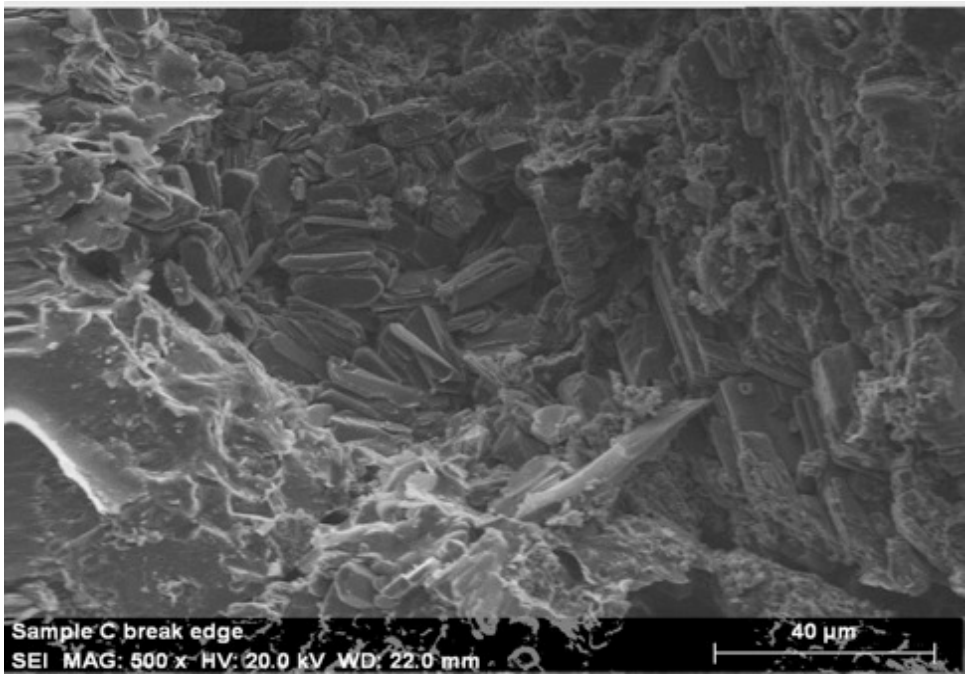

Figure 5.12 SEM photomicrograph of the broken edge of the unweathered sample C (500x). In the center a large number of platy looking particles.

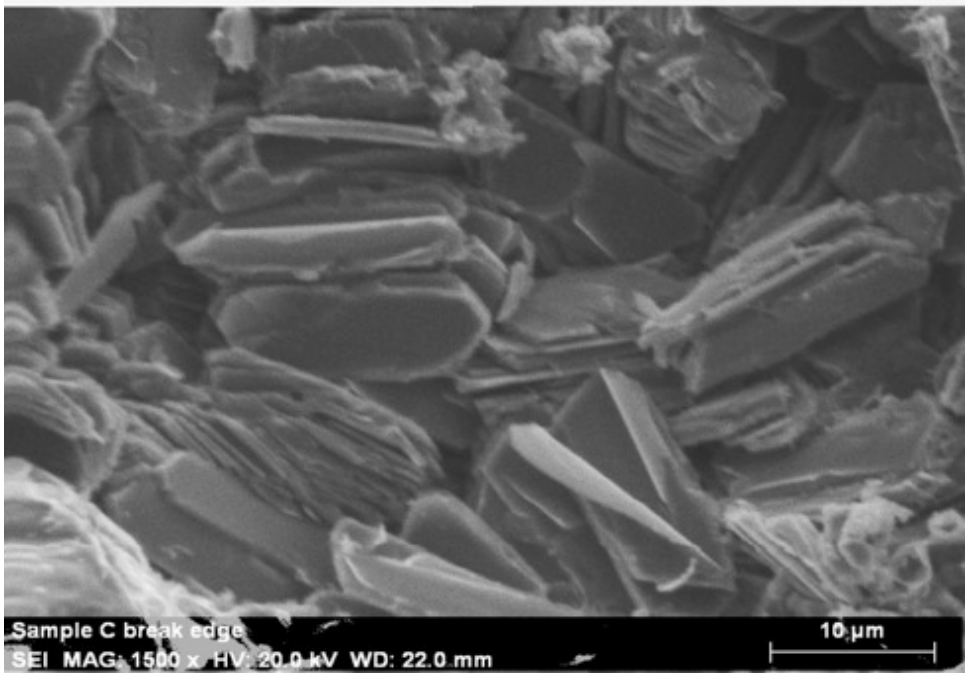

Figure 5.13 Detail of the previous photomicrograph at higher magnification (1500x) showing that the platy particles are clay booklets.

This last figure is an example of feldspars weathering into clay in a process known as kaolinization. The kaolin minerals are platy and book-like as opposed to elongated, suggesting that the kaolinization in this sample is due to a long-term geo-chemical process (as opposed to a "shorter-term kinetic process").[65]

The scanning electron images of the treated samples are shown below. The Prosoco OH100 treated samples are shown in Figures 5.14 to 5.16. The appearance of the elastified consolidant, Remmers KSE 300 E is shown in Figures 5.17 to 5.19.

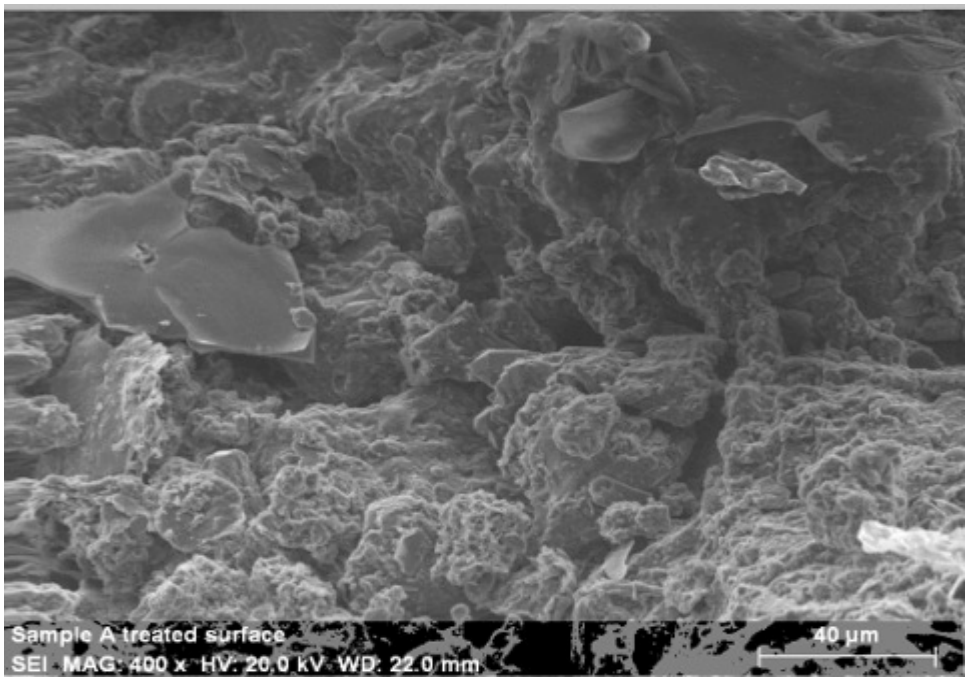

Figure 5.14 SEM photomicrograph of a sample treated with Prosoco OH100 at 400x. Consolidant can be seen as sheets in the top right corner and the center left side. In the instance of the upper right corner, it can be seen that the coating is peeling off from a grain underneath it.

[65] Keller, W.D. *Kaolinization of feldspar as displayed in scanning electron micrographs.* Geology v6 i3. March 1978, 184-188.

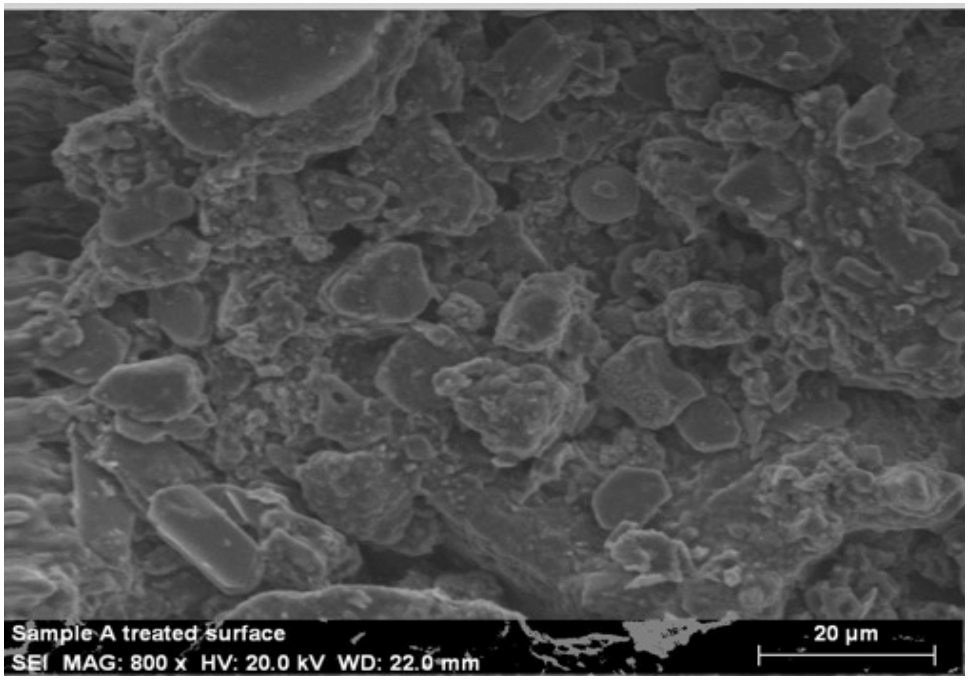

Figure 5.15 A higher magnification view (800 x) of the same sample in Figure 5.14. It is hard to determined whether the particles are coated or not by the Prosoco consolidant.

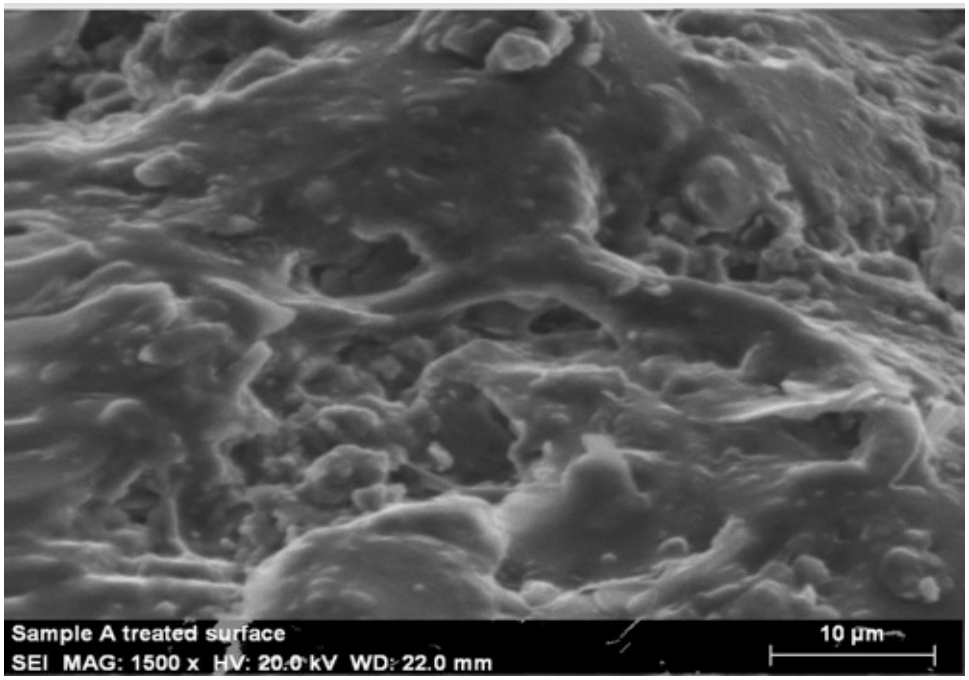

Figure 5.16 A higher magnification view shows that indeed the consolidant has coated the samples, although not uniformly (1500X).

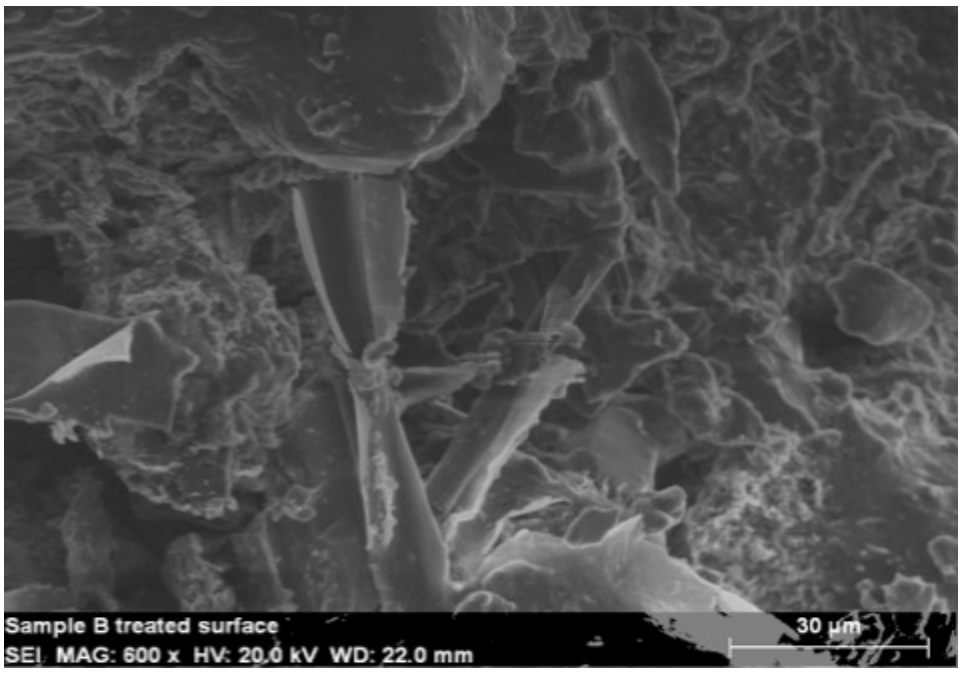

Figure 5.17 SEM photomicrograph of the Remmers treated sample (600x). The consolidant is visible in a strand that bridges two particles, and also in flakes, center left and bottom.

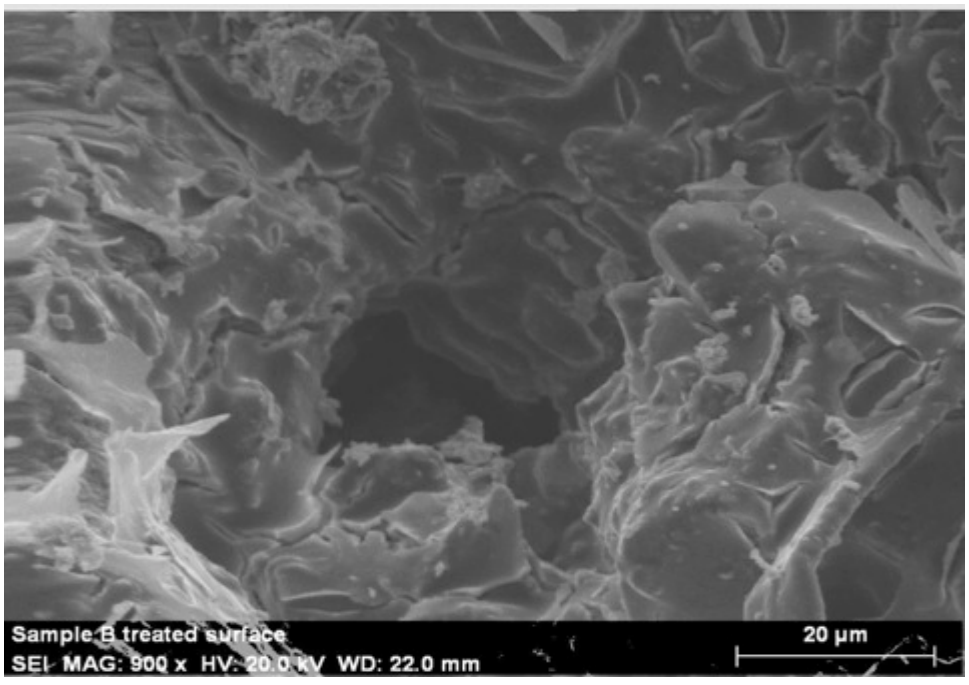

Figure 5.18 A higher magnification view of the Remmers KSE 300 E treated sample (900x)**.** The consolidant coating is clearly visible lining the pore opening in the center of the figure and the surrounding mineral grains. This is in contrast to that of the Prosoco OH100 treated sample (Figure 5.15 at 800x).

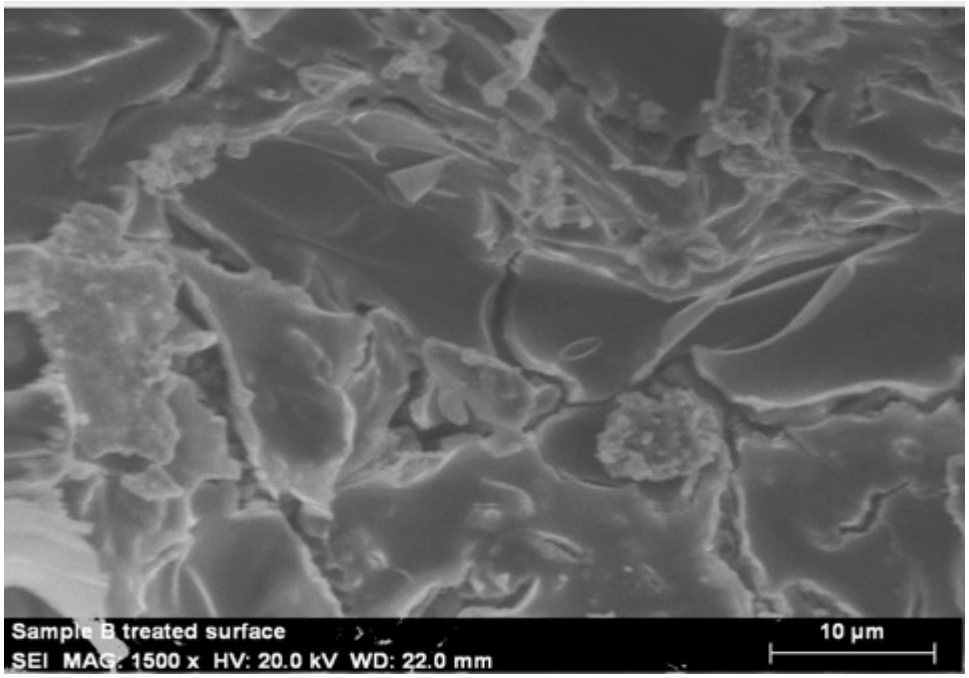

Figure 5.19 A higher magnification shows that the Remmers consolidant provides a uniform coating with the typical shrinkage cracks that provide secondary porosity (1500x).

The conclusion that can be drawn from the SEM examination is that the Remmers KSE 300 E consolidant coated the sample in a more uniform and complete manner than the Prosoco plain ethyl silicate. Furthermore, it appears to be able to bridge larger gaps (see Figure 5.17). It is important to note that both consolidants show relatively poor adhesion in some areas as visible by the peeling off of the consolidant coating from the grain surfaces.

5.6 Resistance Drill Testing

A cordless drill resistance measurement system (DRMS) was used to obtain strength profiles of the treated and untreated cubes, which represented an unweathered surface. Figure 5.20 shows the results obtained with a drill bit of 1/8" and Figure 5.21 used a carbide tip drill bit of 7/32. The same parameters of rotation (900 RPM) and advancing speed (10 mm/min) were applied to each. Interestingly they give different results, which may simply be due to the non- homogeneity of the stone.

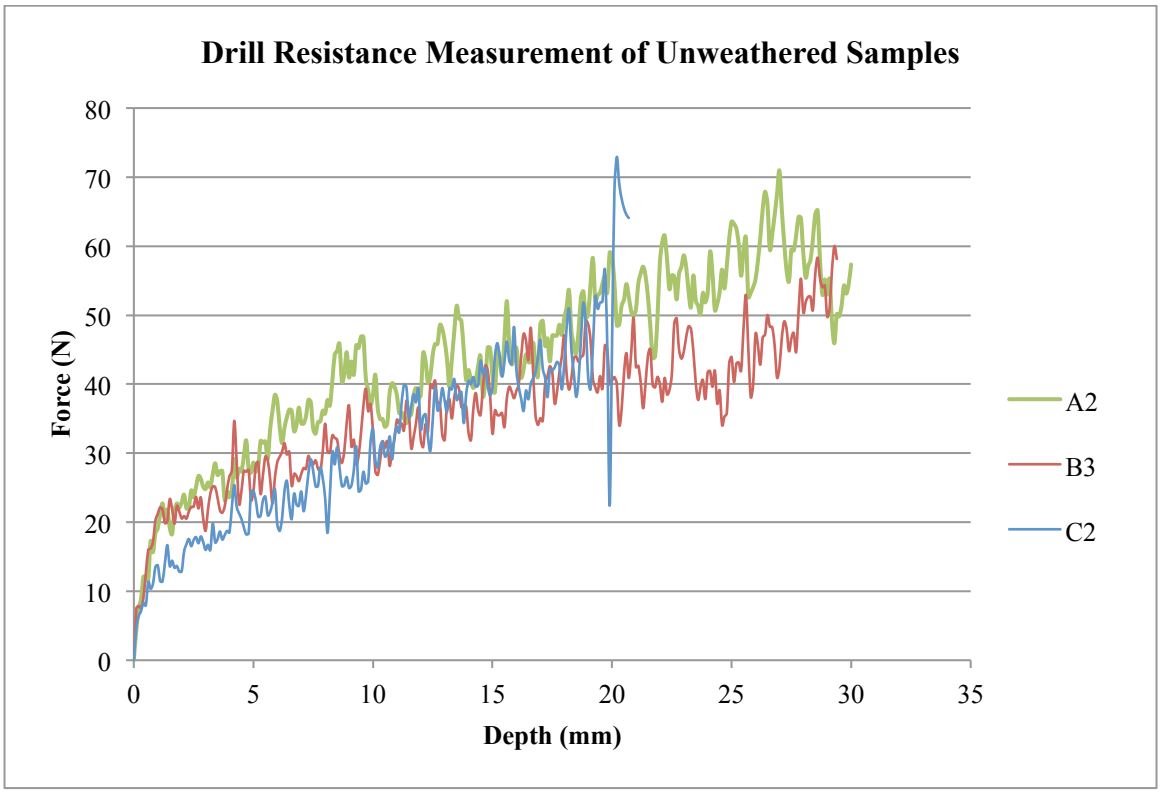

Figure 5.20 Graph showing three drill resistance measurements taken on selected cube samples after about 16 weeks of cure time. The selected samples include A2 (Prosoco OH00) B3 (Remmers KSE 300 E), and C2 (untreated). A new drill bit (1/8") was used for each bore.

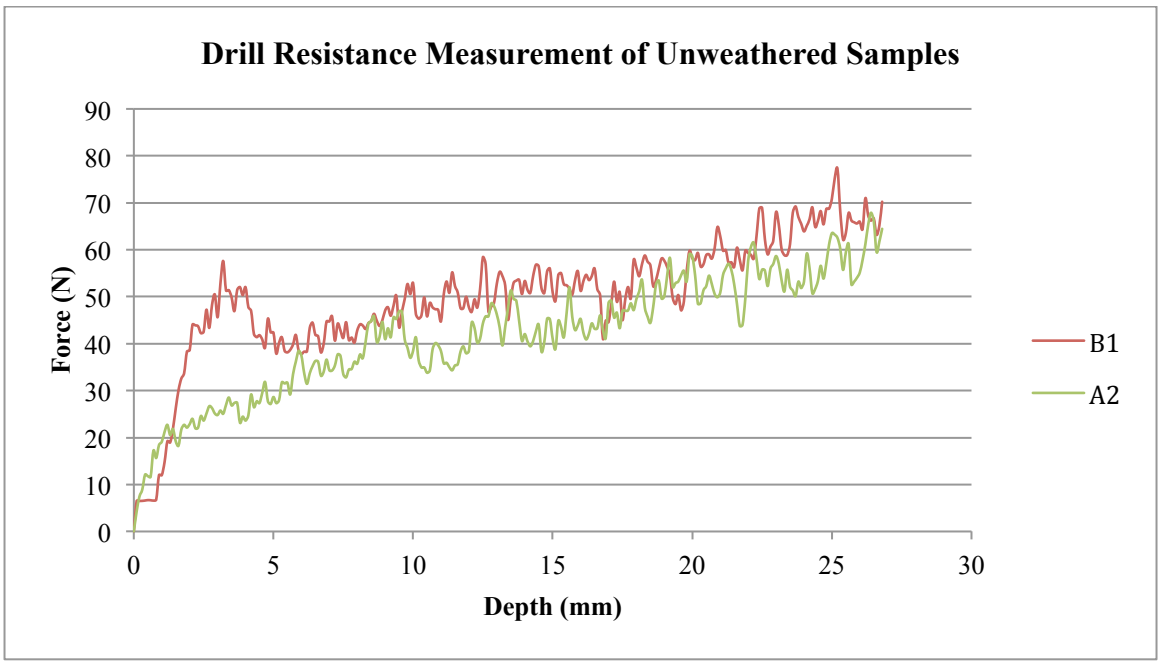

Figure 5.21 The graph shows strength profiles for two treated cube samples, A2 (Prosoco OH100) and B1 (Remmers KSE 300 E). This data was collected using a Champion 7/32" masonry percussion carbide-tipped drill bit after approximately 16 weeks of curing. A new bit was used for each bore.

The results obtained on the unweathered samples showed that both consolidation treatments resulted in a strength increase. The sample treated with OH100 imparted the greatest strength increase as indicated in Figure 5.20. However Figure 5.21 shows a test carried out using a drill bit with a larger diameter on the same Prosoco treated sample and a different (B3) Remmers treated sample. In this instance, the Remmers KSE 300 E resulted in a strength increase over the Prosoco OH100.[66] This reflects both the unhomogeneity of the stone and the applied treatments. More data should be obtained from each of the treated samples to ensure that these results are accurate.

[66] Technical difficulties of the DRMS, such as a faulty battery, combined with a limited time frame prevented further investigation.

Both untreated and treated areas of bulk sample "B" were tested. For this sample, 1/8" drill bits were used under the same conditions mentioned previously to evaluate both untreated and treated areas. The resulting graphs are shown in Figure 5.22

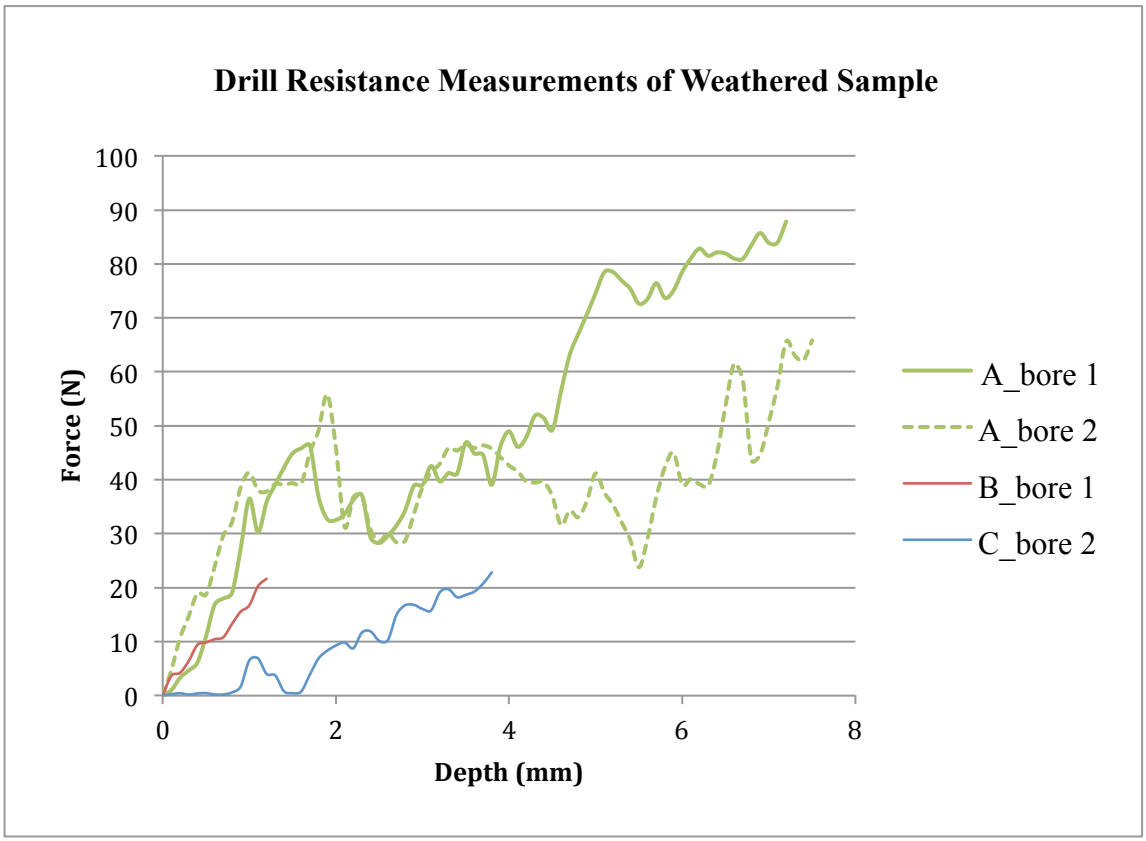

Figure 5.22 Graph showing drill resistance measurements taken on the bulk sample "B" from the weathered surface after about 16 weeks of curing. A is the area treated with Prosoco OH100, B is the Remmers KSE 300 E treated area, and C is the untreated (control). A new bit (1/8") was used for each bore.

The DRMS was able to penetrate the untreated portion of the weathered bulk sample B to a depth of 3.8mm, while it was able to reach 7.5mm for the area treated with Prosoco OH 100 and only 1.2mm for the area treated with Remmers KSE 300 E. Data was not obtained beyond these points because the force required exceeded 100 N. This data is insufficient to describe the depth of penetration, however it does show that a strength increase was imparted within first 1-3 mm by the two treatments. It would be

desirable to obtain more drilling profiles to make broader and more statistically valid conclusions.

The graphs show that with increased depth there is an increase in the force necessary to do the drilling. This increase probably reflects the increase in dust within the bore that hampers the drilling. Figure 5.23 shows the trend lines calculated for this effect for the case of an unweathered cube treated with Remmers KSE E300 using a carbide tip 7/32" drill bit. The graph also shows, that with each re-use of the bit, more force is necessary to carry out the drilling due to the wear of the bit by the abrasion suffered from the quartz grains.

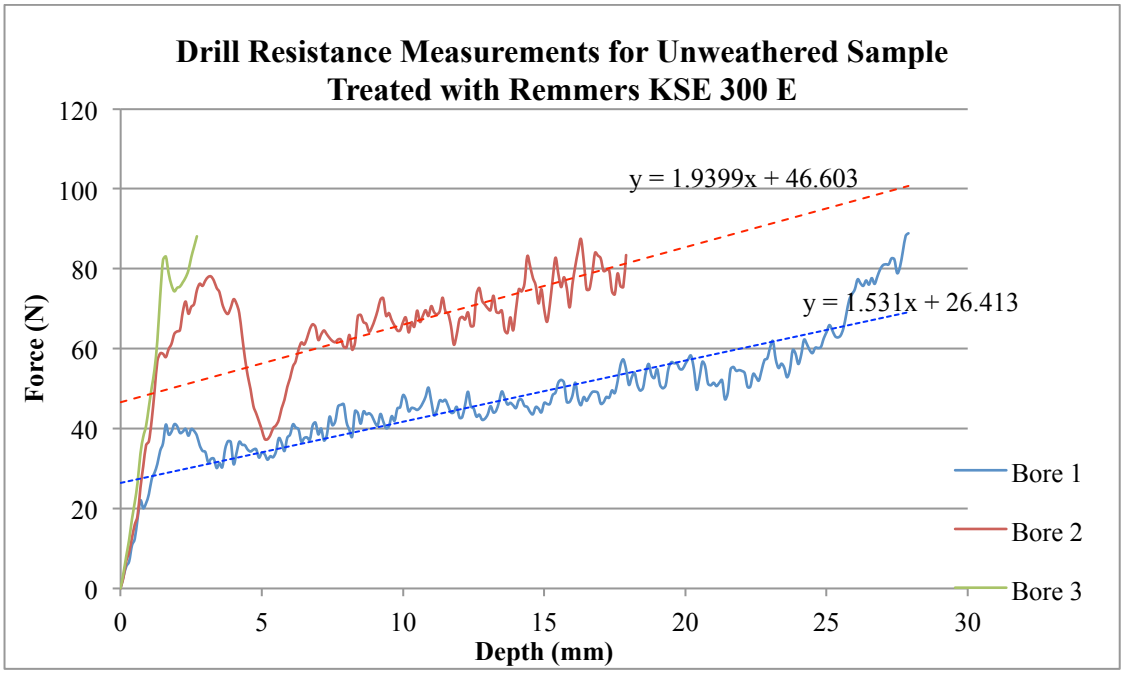

Figure 5.23 Graph showing perceived correlation of strength increase with depth of penetration. However, this is likely due to dust accumulation. Note also the evidence of drill bit wear with each consecutive bore. The same carbide-tipped bit was used for each drill attempt shown in this graph.

Figure 5.24 shows the results obtained by using a carbide-tipped 3mm bit provided by SINT that had been used for approximately 10-15 bores on a similar stone

prior to this test. It was used first on the control area to drill 6 holes, then on the Remmers consolidated area for 5 bores and finally, on the Prosoco treated area for 2 bores. The figure shows the first hole drilled for each area. Unlike the other data, these tests were run at 600 RPM at a penetration rate of 10 mm/min. The full graph showing all bores is included in Appendix D. It can be seen that the untreated area is "softer" than either the consolidated ones, and these are very similar in hardness as the curves overlap confirming that the consolidants improved the mechanical resistance of the stone to a depth of at least 1 cm for the Remmers and nearly 2.5 cm for the Prosoco.

While there is limited data available on DRMS tests for argillaceous sandstone, some studies, such as the "Schilfsanstein" of Germany, list the compressive strength, among other characteristics, for clay-rich sandstone. For sandstone with mainly a clay binder, the compressive strength averages 74 $N/mm^{2,}$ on a dry sample. A more loosely packed and porous sandstone exhibiting characteristics of sanding had an average compressive strength vertical to the bedding of 37-39 N/mm^2 and 28 N/mm^2 parallel to the bedding.[67] Although comparative data is useful, for the purposes of this thesis, the important comparison is between untreated and treated samples of the same stone.

[67] Visser, H., A. Gervais, J. Lepper, E. Stadbauer, R. Niemyer, A. Ehling, J. Schubert, H. Argow, and A. Pohlmann. "Petrography, composition and characteristics of "schilfsanstein" with particular reference to north west Germany and weathering behaviour in historic buildings". *11th International Congress on Deterioration and Conservation of Stone.* Eds. Lukaszewicz, J and Niemcewicz, P. Torun, Poland: 2008, 827-836.

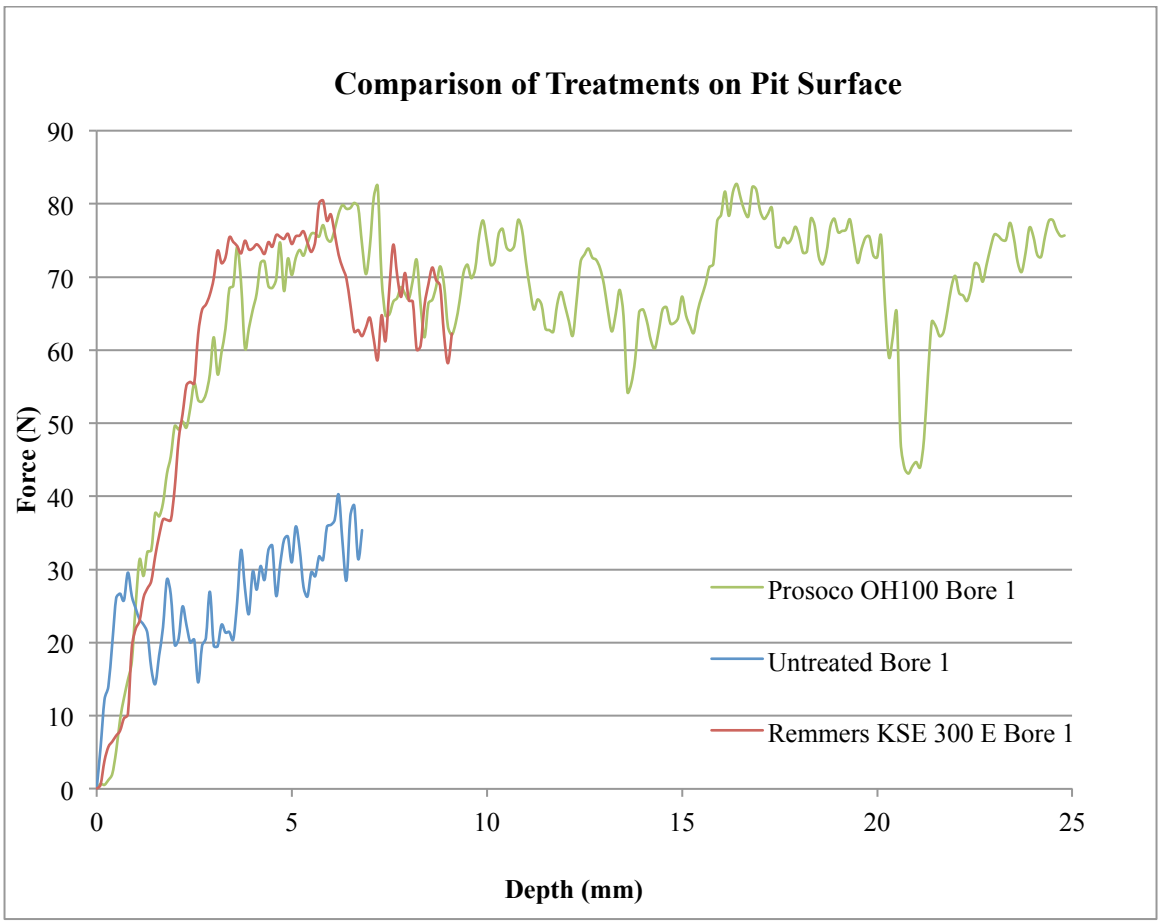

Figure 5.24 Graph showing initial attempt to determine depth of penetration on bulk sample B. There is a noticeable difference in hardness between the treated and untreated stone and both consolidants appear to provide the same strengthening effect. The same carbide-tipped 3mm bit provided by SINT was used for all bores.

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

This study has shown that both consolidation treatments, Remmers KSE 300 E and Prosoco OH100, increase the hardness of the sandstone samples from Durham Castle. However both of the treatments also reduce the permeance, water absorption and drying behavior of the stone. Only one treatment, the Prosoco OH100 alters the color of the stone.

The wetting and drying behavior of the two treatments is similar, they both reduce the amount of water absorbed by capillarity as well as that retained by the stone after total immersion, The Remmers KSE 300 E treatment altered the behavior of the stone slightly more than the Prosoco OH100 treatment, in particular it took up less capillary water, but once it was saturated with water it retained more than the Prosoco treated one though still less than the untreated sample. The water vapor transmission testing showed that the permeance of the treated samples is reduced to half of an untreated stone, for both Remmers and Prosoco, with that of the Remmers treated samples being slightly lower.

The Prosoco OH100 treatment provided the greatest increase in hardness, as was evidenced by the resistance drill measurement system (DRMS). It should be noted that on an unweathered surface, the two treatments provided similar hardness increases for the first 5 mm from the surface, however, after approximately 20mm, it appears that the Remmers treatment did not impart the same strength increase as the Prosoco treatment. On the weathered surface, both treatments showed a hardness increase compared to an untreated area. However due to limitations of the drill at the time of testing, the data is inconclusive regarding the depth of penetration and hardness increase for a weathered

surface. From the data available, it is likely that the Prosoco OH100 treatment provided the greatest strength increase.

Differences between the two treatments were visually confirmed using SEM, which showed that the Remmers KSE 300 E more uniformly coated mineral grains, with some shrinkage cracking and an ability to bridge large gaps. Both consolidants showed poor adhesion to mineral grains.

Lastly, the Prosoco OH100 altered the surface color of the stone more significantly than the Remmers KSE 300 E treatment, which showed almost no color change. The Prosoco treatment yellowed and darkened the weathered stone significantly. It showed only slight darkening of the unweathered samples. It is assumed that exposure to UV light (sunlight) would diminish this effect over time.

Thus, with the data obtained so far it would be difficult to make a choice between the two products, as there are both advantages and disadvantages to each product.

6.2 Recommendations for Future Research

The key problem affecting the sandstone of Durham Castle is the alveolar deterioration it suffers. As mentioned, one of the problems is the heterogeneity of the stone, in that it may contain a calcareous binder and/or an argillaceous one. In the first case, it would be useful to determine, based on the condition survey carried out, whether there is any correlation between the amount of calcareous binder, or the amount of clays present, and the degree of alveolar deterioration.

Should a correlation be established, for example, that stones containing a high calcitic binder are the ones that preferentially develop alveolar weathering, then the key process could be attributed most likely to air pollution and the consequent presence of

gypsum. In such a case, it would be useful to test methods that immobilize the sulfate, as for example the Florentine method developed for mural paintings.[68] This method, apart from immobilizing gypsum with barium hydroxide, includes consolidation with ammonium oxalate that will only work in the case of the calcareous binder, but since the loss of binder is the problem it may well serve to reduce the deterioration rate of sound stone provided it has a significant amount of binder. On the other hand, if a correlation is found with the presence and amount of expanding clays, then treatment with an anti-swelling product should be tested, as previously mentioned.

Since it was observed that the silicate ester, either the simple Prosoco OH100 or the elastified Remmers KSE 300E, showed poor adhesion to the mineral surfaces, application of an adhesive coupling agent should also be tested. There are various products that are being developed that will improve the bonding between these consolidants and the silicate minerals. Therefore a testing program should be developed that includes the application of these products plus the silicate esters. From the results obtained, it appears that their simple application improves the strength of the stone but decreases its water vapor permeability and water retention. If an anti-swelling product is also applied, this may well improve the behavior of the consolidants.[69] Finally, all of these mentioned treatments, immobilization of gypsum, consolidation of the calcareous binder with ammonium oxalate, antiswelling treatment for the ubiquitous clays in this stone, and adhexive coupling agents could well be applied in a properly sequential

[68] Matteini, Mauro. "The mineral approach to the conservation of mural paintings: barium hydroxide and artificial oxalates". *Conserving the painted past: developing approaches to wall painting conservation: post-prints of a conference organized by English Heritage, London, 2-4 December, 1999*. Eds. Gowing, Robert and Adrian Heritage. London:James & James. (2003), 110-115.
[69] Remmers recommends the use of Funcosil Antihygro (manufactured by Remmers) as a pretreatment to the KSE 300 E, see Remmers Product Information Sheet for KSE 300 E.

manner. And then, the behavior of the two consolidants would have to be evaluated on these pretreated samples.

In conclusion, the most important next step is to correlate the alveolar deterioration on specific blocks to the actual binder composition since the loss of binder (or cementing matrix) is the cause of the deterioration.

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Appendix A CAPILLARY WATER ABSORPTION & TOTAL IMMERSION **SAMPLE A1**
TREATMENT: PROSOCO OH100

W_{dry} (g)	W_{max} (g)	U_o (g) W_{max}-W_{dry}
297.2	306.5	9.3

Imbibition Capacity	% Apparent Porosity	% Open Porosity
0.031	3.1	7.44

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12	7:40 AM	0.00	0.00	297.23	0.00	0.00
4/13/12	7:45 AM	300.00	17.32	297.32	0.09	0.00
4/13/12	7:50 AM	600.00	24.49	297.36	0.13	0.01
4/13/12	7:55 AM	900.00	30.00	297.41	0.18	0.01
4/13/12	8:00 AM	1200.00	34.64	297.44	0.21	0.01
4/13/12	8:05 AM	1500.00	38.73	297.46	0.23	0.01
4/13/12	8:10 AM	1800.00	42.43	297.48	0.25	0.01
4/13/12	8:15 AM	2100.00	45.83	297.50	0.27	0.01
4/13/12	8:25 AM	2700.00	51.96	297.53	0.30	0.01
4/13/12	8:40 AM	3600.00	60.00	297.56	0.33	0.01
4/13/12	9:10 AM	5400.00	73.48	297.63	0.40	0.02
4/13/12	9:40 AM	7200.00	84.85	297.70	0.47	0.02
4/13/12	10:10 AM	9000.00	94.87	297.77	0.54	0.02

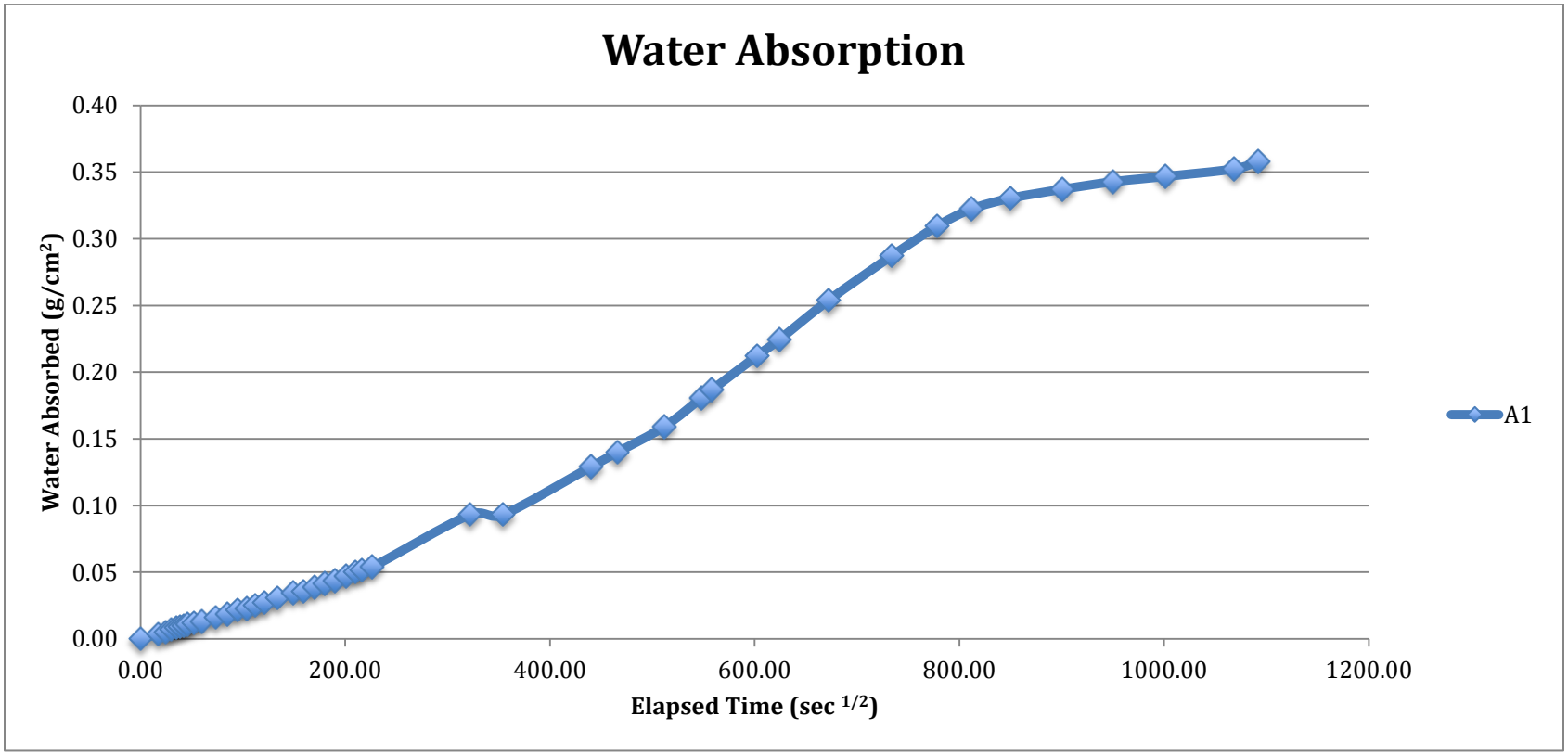
APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE A1 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12	10:40 AM	10800.00	103.92	297.80	0.57	0.02
4/13/12	11:10 AM	12600.00	112.25	297.86	0.63	0.03
4/13/12	11:45 AM	14700.00	121.24	297.91	0.68	0.03
4/13/12	12:40 AM	18000.00	134.16	298.00	0.77	0.03
4/13/12	1:48 PM	22200.00	149.00	298.09	0.86	0.03
4/13/12	2:40 PM	25200.00	158.75	298.12	0.89	0.04
4/13/12	3:40 PM	28800.00	169.71	298.20	0.97	0.04
4/13/12	4:40 PM	32400.00	180.00	298.27	1.04	0.04
4/13/12	5:40 PM	36000.00	189.74	298.32	1.09	0.04
4/13/12	6:53 PM	40440.00	201.10	298.41	1.18	0.05
4/13/12	7:52 PM	43980.00	209.71	298.48	1.25	0.05
4/13/12	8:40 PM	46800.00	216.33	298.52	1.29	0.05
4/13/12	9:55 PM	51300.00	226.50	298.58	1.35	0.05
4/14/12	12:26 PM	103560.00	321.81	299.31	2.08	0.08
4/14/12	6:28 PM	125220.00	353.86	299.56	2.33	0.09
4/15/12	1:31 PM	193620.00	440.02	300.46	3.23	0.13
4/15/12	8:00 PM	217200.00	466.05	300.73	3.50	0.14
4/16/12	8:24 AM	261840.00	511.70	301.21	3.98	0.16
4/16/12	7:07 PM	300420.00	548.11	301.75	4.52	0.18
4/16/12	10:14 PM	311640.00	558.25	301.90	4.67	0.19
4/17/12	12:28 PM	362880.00	602.40	302.54	5.31	0.21
4/17/12	7:47 PM	389220.00	623.87	302.84	5.61	0.22

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE A1 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/18/12	1:12 PM	451920.00	672.25	303.58	6.35	0.25
4/19/12	1:16 PM	538560.00	733.87	304.41	7.18	0.29
4/20/12	7:59 AM	605880.00	778.38	304.97	7.74	0.31
4/20/12	10:47 PM	659160.00	811.89	305.29	8.06	0.32
4/21/12	4:14 PM	721980.00	849.69	305.49	8.26	0.33
4/22/12	5:04 PM	811380.00	900.77	305.66	8.43	0.34
4/23/12	6:21 PM	902400.00	949.95	305.80	8.57	0.34
4/24/12	10:10 PM	1002540.00	1001.27	305.90	8.67	0.35
4/26/12		1141320.00	1068.33	306.04	8.81	0.35
4/27/12	4:52 AM	1192260.00	1091.91	306.18	8.95	0.36

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE A1 (CONTINUED)



Appendix A CAPILLARY WATER ABSORPTION & TOTAL IMMERSION **SAMPLE A2**
TREATMENT: PROSOCO OH100

W_{dry} (g)	W_{max} (g)	U_o (g) W_{max}-W_{dry}
318.5	326.7	8.2

Imbibition Capacity	% Apparent Porosity	% Open Porosity
0.026	2.6	6.56

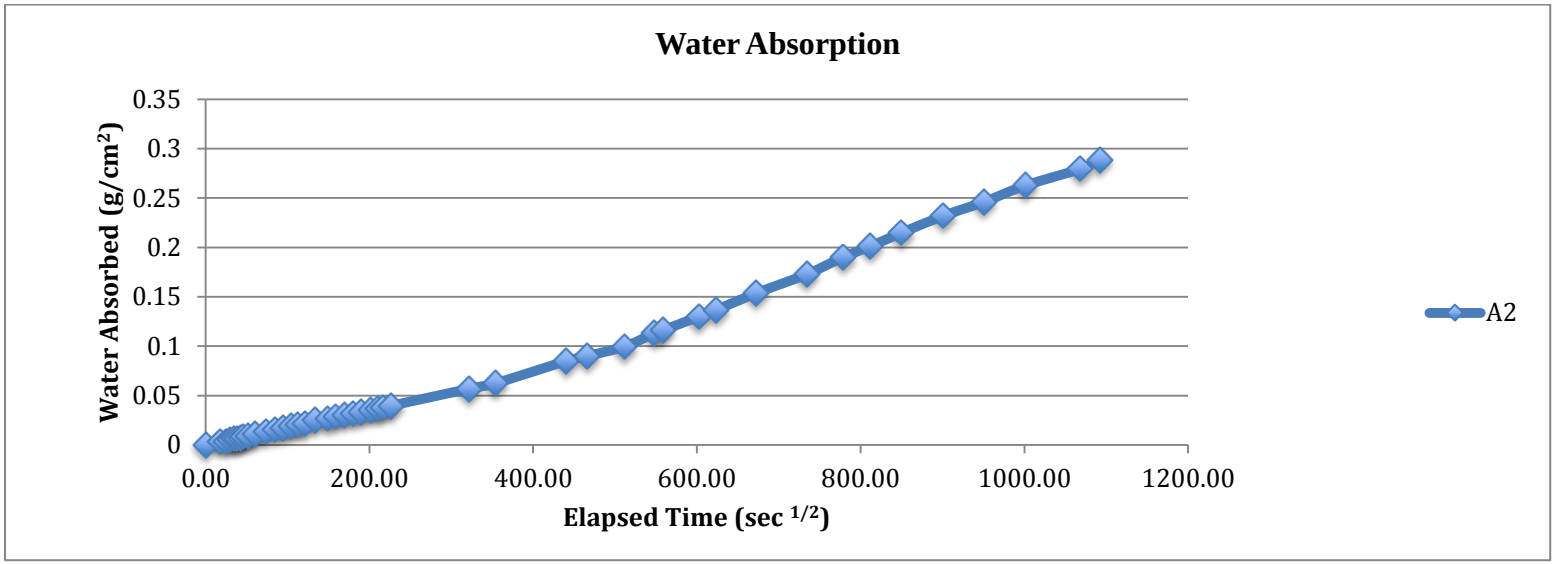
DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12	7:40 AM	0.00	0.00	318.45	0.00	0
4/13/12	7:45 AM	300.00	17.32	318.54	0.09	0.0036
4/13/12	7:50 AM	600.00	24.49	318.54	0.09	0.0036
4/13/12	7:55 AM	900.00	30.00	318.58	0.13	0.0052
4/13/12	8:00 AM	1200.00	34.64	318.61	0.16	0.0064
4/13/12	8:05 AM	1500.00	38.73	318.61	0.16	0.0064
4/13/12	8:10 AM	1800.00	42.43	318.63	0.18	0.0072
4/13/12	8:15 AM	2100.00	45.83	318.66	0.21	0.0084
4/13/12	8:25 AM	2700.00	51.96	318.67	0.22	0.0088
4/13/12	8:40 AM	3600.00	60.00	318.72	0.27	0.0108
4/13/12	9:10 AM	5400.00	73.48	318.79	0.34	0.0136
4/13/12	9:40 AM	7200.00	84.85	318.84	0.39	0.0156
4/13/12	10:10 AM	9000.00	94.87	318.88	0.43	0.0172
4/13/12	10:40 AM	10800.00	103.92	318.92	0.47	0.0188
4/13/12	11:10 AM	12600.00	112.25	318.96	0.51	0.0204
4/13/12	11:45 AM	14700.00	121.24	318.99	0.54	0.0216
4/13/12	12:40 AM	18000.00	134.16	319.08	0.63	0.0252
4/13/12	1:48 PM	22200.00	149.00	319.11	0.66	0.0264

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE A2 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (gr)	Mi (g/cm^2)
4/13/12	2:40 PM	25200.00	158.75	319.16	0.71	0.0284
4/13/12	3:40 PM	28800.00	169.71	319.20	0.75	0.03
4/13/12	4:40 PM	32400.00	180.00	319.24	0.79	0.0316
4/13/12	5:40 PM	36000.00	189.74	319.28	0.83	0.0332
4/13/12	6:53 PM	40440.00	201.10	319.33	0.88	0.0352
4/13/12	7:52 PM	43980.00	209.71	319.37	0.92	0.0368
4/13/12	8:40 PM	46800.00	216.33	319.39	0.94	0.0376
4/13/12	9:55 PM	51300.00	226.50	319.44	0.99	0.0396
4/14/12	12:26 PM	103560.00	321.81	319.87	1.42	0.0568
4/14/12	6:28 PM	125280.00	353.95	320.01	1.56	0.0624
4/15/12	1:31 PM	193860.00	440.30	320.57	2.12	0.0848
4/15/12	8:00 PM	217020.00	465.85	320.70	2.25	0.09
4/16/12	8:24 AM	261840.00	511.70	320.94	2.49	0.0996
4/16/12	7:07 PM	300420.00	548.11	321.28	2.83	0.1132
4/16/12	10:14 PM	311640.00	558.25	321.35	2.90	0.116
4/17/12	12:28 PM	362880.00	602.40	321.70	3.25	0.13
4/17/12	7:47 PM	389220.00	623.87	321.87	3.42	0.1368
4/18/12	1:12 PM	451920.00	672.25	322.29	3.84	0.1536
4/19/12		538560.00	733.87	322.77	4.32	0.1728
4/20/12	7:59 AM	605880.00	778.38	323.20	4.75	0.19
4/20/12	10:47 PM	659160.00	811.89	323.48	5.03	0.2012
4/21/12	4:14 PM	721980.00	849.69	323.82	5.37	0.2148

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE A2 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (gr)	Mi (g/cm^2)
4/22/12	5:04 PM	811380.00	900.77	324.25	5.80	0.232
4/23/12		902400.00	949.95	324.60	6.15	0.246
4/24/12	10:10 PM	1002540.00	1001.27	325.02	6.57	0.2628
4/26/12		1141320.00	1068.33	325.44	6.99	0.2796
4/27/12	4:52 AM	1192260.00	1091.91	325.66	7.21	0.2884



Appendix A CAPILLARY WATER ABSORPTION & TOTAL IMMERSION **SAMPLE A3**
TREATMENT: PROSOCO OH100

W_{dry} (g)	W_{max} (g)	U_o (g) W_{max}-W_{dry}
307.6	315.6	8.1

Imbibition Capacity	% Apparent Porosity	% Open Porosity
0.026	2.6	6.48

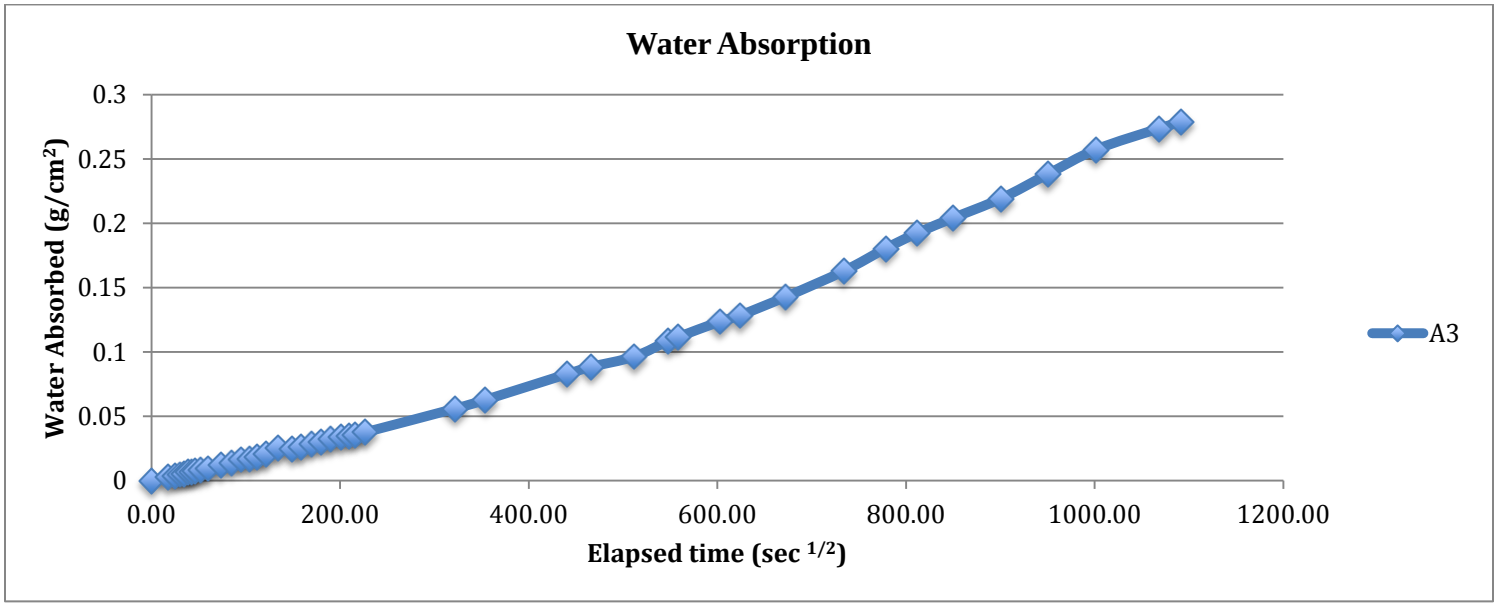
DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12	7:40 AM	0.00	0.00	307.55	0.00	0
4/13/12	7:45 AM	300.00	17.32	307.61	0.06	0.0024
4/13/12	7:50 AM	600.00	24.49	307.64	0.09	0.0036
4/13/12	7:55 AM	900.00	30.00	307.67	0.12	0.0048
4/13/12	8:00 AM	1200.00	34.64	307.68	0.13	0.0052
4/13/12	8:05 AM	1500.00	38.73	307.71	0.16	0.0064
4/13/12	8:10 AM	1800.00	42.43	307.72	0.17	0.0068
4/13/12	8:15 AM	2100.00	45.83	307.73	0.18	0.0072
4/13/12	8:25 AM	2700.00	51.96	307.75	0.20	0.008
4/13/12	8:40 AM	3600.00	60.00	307.79	0.24	0.0096
4/13/12	9:10 AM	5400.00	73.48	307.85	0.30	0.012
4/13/12	9:40 AM	7200.00	84.85	307.90	0.35	0.014
4/13/12	10:10 AM	9000.00	94.87	307.96	0.41	0.0164
4/13/12	10:40 AM	10800.00	103.92	307.97	0.42	0.0168
4/13/12	11:10 AM	12600.00	112.25	308.02	0.47	0.0188
4/13/12	11:45 AM	14700.00	121.24	308.06	0.51	0.0204
4/13/12	12:40 AM	18000.00	134.16	308.18	0.63	0.0252
4/13/12	1:48 PM	22200.00	149.00	308.16	0.61	0.0244

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE A3 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12	2:40 PM	25200.00	158.75	308.20	0.65	0.026
4/13/12	3:40 PM	28800.00	169.71	308.26	0.71	0.0284
4/13/12	4:40 PM	32400.00	180.00	308.30	0.75	0.03
4/13/12	5:40 PM	36000.00	189.74	308.35	0.80	0.032
4/13/12	6:53 PM	40440.00	201.10	308.39	0.84	0.0336
4/13/12	7:52 PM	43980.00	209.71	308.42	0.87	0.0348
4/13/12	8:40 PM	46800.00	216.33	308.44	0.89	0.0356
4/13/12	9:55 PM	51300.00	226.50	308.49	0.94	0.0376
4/14/12	12:26 PM	103560.00	321.81	308.95	1.40	0.056
4/14/12	6:28 PM	125220.00	353.95	309.12	1.57	0.0628
4/15/12	1:31 PM	193620.00	440.30	309.62	2.07	0.0828
4/15/12	8:00 PM	217200.00	465.85	309.76	2.21	0.0884
4/16/12	8:24 AM	269100.00	511.70	309.96	2.41	0.0964
4/16/12	7:07 PM	270453.00	548.11	310.27	2.72	0.1088
4/16/12	10:14 PM	270640.00	558.25	310.34	2.79	0.1116
4/17/12	12:28 PM	271494.00	602.40	310.64	3.09	0.1236
4/17/12	7:47 PM	271933.00	623.87	310.76	3.21	0.1284
4/18/12	1:12 PM	272978.00	672.25	311.12	3.57	0.1428
4/19/12		538620.00	733.87	311.62	4.07	0.1628
4/20/12	7:59 AM	605940.00	778.38	312.06	4.51	0.1804
4/20/12	10:47 PM	659220.00	811.89	312.36	4.81	0.1924
4/21/12	4:14 PM	722040.00	849.69	312.65	5.10	0.204

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE A3 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/22/12	5:04 PM	811500.00	900.77	313.03	5.48	0.2192
4/23/12		902520.00	949.95	313.50	5.95	0.238
4/24/12	10:10 PM	1002720.00	1001.27	313.98	6.43	0.2572
4/26/12		1141500.00	1068.33	314.39	6.84	0.2736
4/27/12	4:52 AM	1199940.00	1091.91	314.52	6.97	0.2788



Appendix A CAPILLARY WATER ABSORPTION& TOTAL IMMERSION **SAMPLE B1**
TREATMENT: REMMERS KSE 300 E

W_{dry} (g)	W_{max} (g)	U_o (g) W_{max}-W_{dry}
301.6	308.8	7.2

Imbibition Capacity	% Apparent Porosity	% Open Porosity
0.024	2.4	5.76

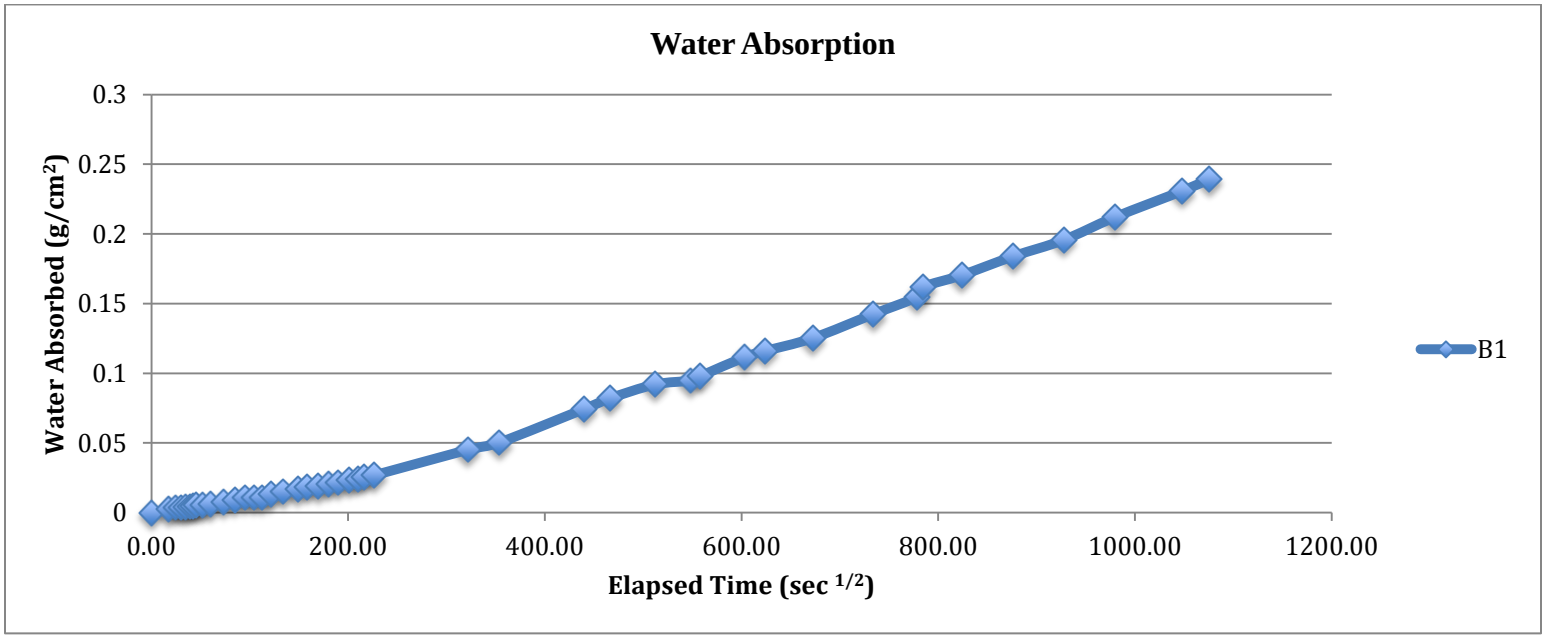
DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12	7:43 AM	0.00	0.00	301.58	0.00	0
4/13/12	7:48 AM	300.00	17.32	301.64	0.06	0.0024
4/13/12	7:53 AM	600.00	24.49	301.67	0.09	0.0036
4/13/12	7:58 AM	900.00	30.00	301.67	0.09	0.0036
4/13/12	8:03 AM	1200.00	34.64	301.68	0.10	0.004
4/13/12	8:08 AM	1500.00	38.73	301.69	0.11	0.0044
4/13/12	8:13 AM	1800.00	42.43	301.70	0.12	0.0048
4/13/12	8:28 AM	2100.00	45.83	301.71	0.13	0.0052
4/13/12	8:42 AM	2700.00	51.96	301.71	0.13	0.0052
4/13/12	9:13 AM	3600.00	60.00	301.73	0.15	0.006
4/13/12	9:42 AM	5400.00	73.48	301.77	0.19	0.0076
4/13/12	10:12 AM	7200.00	84.85	301.81	0.23	0.0092
4/13/12	11:02 AM	9000.00	94.87	301.85	0.27	0.0108
4/13/12	11:13 AM	10800.00	103.92	301.85	0.27	0.0108
4/13/12	11:46 AM	12600.00	112.25	301.85	0.27	0.0108
4/13/12	12:43 PM	14700.00	121.24	301.91	0.33	0.0132
4/13/12	1:48 PM	18000.00	134.16	301.96	0.38	0.0152
4/13/12	2:43 PM	22200.00	149.00	302.00	0.42	0.0168

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE B1 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12	3:43 PM	25200.00	158.75	302.04	0.46	0.0184
4/13/12		28800.00	169.71	302.05	0.47	0.0188
4/13/12		32400.00	180.00	302.10	0.52	0.0208
4/13/12		36000.00	189.74	302.12	0.54	0.0216
4/13/12		40440.00	201.10	302.16	0.58	0.0232
4/13/12		43980.00	209.71	302.19	0.61	0.0244
4/13/12		46800.00	216.33	302.22	0.64	0.0256
4/13/12		51180.00	226.23	302.25	0.67	0.0268
4/14/12		103500.00	321.71	302.71	1.13	0.0452
4/14/12		125220.00	353.86	302.84	1.26	0.0504
4/15/12	1:29 PM	193500.00	439.89	303.44	1.86	0.0744
4/15/12	8:02 PM	217140.00	465.98	303.63	2.05	0.082
4/16/12	8:29 AM	261900.00	511.76	303.88	2.30	0.092
4/16/12	7:10 PM	300360.00	548.05	303.95	2.37	0.0948
4/16/12	10:17 PM	311580.00	558.19	304.03	2.45	0.098
4/17/12	12:45 PM	363660.00	603.04	304.37	2.79	0.1116
4/17/12	7:50 PM	389160.00	623.83	304.48	2.90	0.116
4/18/12	1:14 PM	451800.00	672.16	304.71	3.13	0.1252
4/19/12	1:17 PM	538380.00	733.74	305.14	3.56	0.1424
4/20/12	8:01 AM	605820.00	778.34	305.45	3.87	0.1548
4/20/12	10:48 PM	615840.00	784.75	305.63	4.05	0.162
4/21/12	4:15 PM	678660.00	823.81	305.84	4.26	0.1704

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE B1 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi ($g/cm^{\wedge 2}$)
4/22/12	5:06 PM	768120.00	876.42	306.18	4.60	0.184
4/23/12	6:36 PM	859920.00	927.32	306.47	4.89	0.1956
4/24/12	10:13 PM	959340.00	979.46	306.88	5.30	0.212
4/26/12	12:46 PM	1098120.00	1047.91	307.35	5.77	0.2308
4/27/12	4:55 AM	1156260.00	1075.30	307.56	5.98	0.2392



Appendix A CAPILLARY WATER ABSORPTION& TOTAL IMMERSION **SAMPLE B2**
TREATMENT: REMMERES KSE 300 300 E

W_{dry} (g)	W_{max} (g)	U_o (g) W_{max}-W_{dry}
311.2	319.4	8.2

Imbibition Capacity	% Apparent Porosity	% Open Porosity
0.026	2.6	6.56

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12	7:43 AM	0.00	0.00	301.58	0.00	0
4/13/12	7:48 AM	300.00	17.32	301.64	0.06	0.0024
4/13/12	7:53 AM	600.00	24.49	301.67	0.09	0.0036
4/13/12	7:58 AM	900.00	30.00	301.67	0.09	0.0036
4/13/12	8:03 AM	1200.00	34.64	301.68	0.10	0.004
4/13/12	8:08 AM	1500.00	38.73	301.69	0.11	0.0044
4/13/12	8:13 AM	1800.00	42.43	301.70	0.12	0.0048
4/13/12	8:18 AM	2100.00	45.83	301.71	0.13	0.0052
4/13/12	8:28 AM	2700.00	51.96	301.71	0.13	0.0052
4/13/12	8:58 AM	3600.00	60.00	301.73	0.15	0.006
4/13/12	9:28 AM	5400.00	73.48	301.77	0.19	0.0076
4/13/12	9:58 AM	7200.00	84.85	301.81	0.23	0.0092
4/13/12	10:28 AM	9000.00	94.87	301.85	0.27	0.0108
4/13/12	10:58 AM	10800.00	103.92	301.85	0.27	0.0108
4/13/12	11:13 AM	12600.00	112.25	301.85	0.27	0.0108
4/13/12	11:46 AM	14700.00	121.24	301.91	0.33	0.0132
4/13/12	12:43 PM	18000.00	134.16	301.96	0.38	0.0152

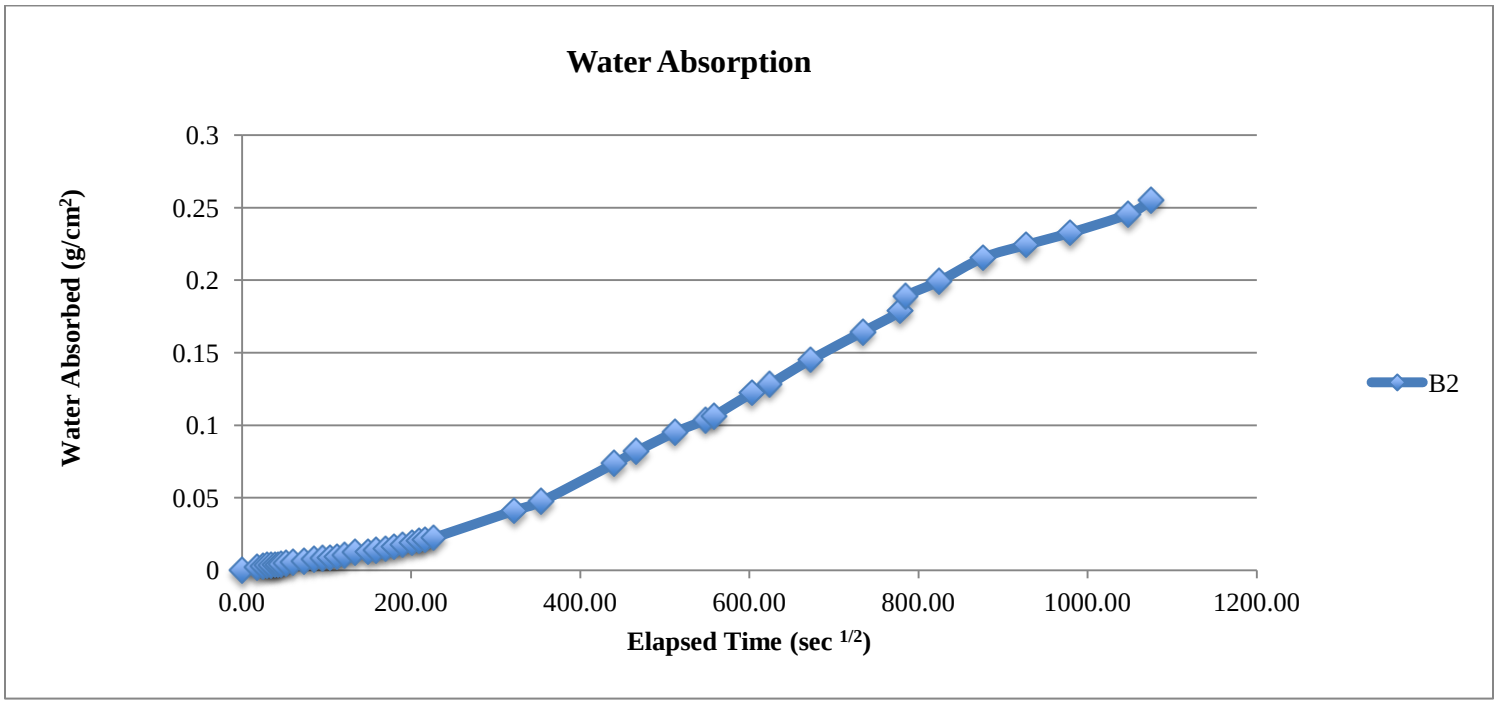
APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE B2 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12	1:48 PM	22200.00	149.00	302.00	0.42	0.0168
4/13/12	2:43 PM	25200.00	158.75	302.04	0.46	0.0184
4/13/12		28800.00	169.71	302.05	0.47	0.0188
4/13/12		32400.00	180.00	302.10	0.52	0.0208
4/13/12		36000.00	189.74	302.12	0.54	0.0216
4/13/12		40440.00	201.10	302.16	0.58	0.0232
4/13/12		43980.00	209.71	302.19	0.61	0.0244
4/13/12		46800.00	216.33	302.22	0.64	0.0256
4/13/12		51180.00	226.23	302.25	0.67	0.0268
4/14/12		103500.00	321.71	302.71	1.13	0.0452
4/14/12		125220.00	353.86	302.84	1.26	0.0504
4/15/12	1:29 PM	193500.00	439.89	303.44	1.86	0.0744
4/15/12	8:02 PM	217140.00	465.98	303.63	2.05	0.082
4/16/12	8:29 AM	261900.00	511.76	303.88	2.30	0.092
4/16/12	7:10 PM	300420.00	548.11	303.95	2.37	0.0948
4/16/12	10:17 PM	311700.00	558.30	304.03	2.45	0.098
4/17/12	12:45 PM	363780.00	603.14	304.37	2.79	0.1116
4/17/12	7:50 PM	389220.00	623.87	304.48	2.90	0.116
4/18/12	1:14 PM	451920.00	672.25	304.71	3.13	0.1252
4/19/12	1:17 PM	538500.00	733.83	305.14	3.56	0.1424
4/20/12	8:01 AM	605880.00	778.38	305.45	3.87	0.1548
4/20/12	10:48 PM	659100.00	811.85	305.63	4.05	0.162

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE B2 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME (SEC $^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/21/12	4:15 PM	721980.00	849.69	305.84	4.26	0.1704
4/22/12	5:06 PM	811440.00	900.80	306.18	4.60	0.184
4/23/12	6:36 PM	903300.00	950.42	306.47	4.89	0.1956
4/24/12	10:13 PM	1002660.00	1001.33	306.88	5.30	0.212
4/26/12	12:46 PM	1141440.00	1068.38	307.35	5.77	0.2308
4/27/12	4:55 AM	1199640.00	1095.28	307.56	5.98	0.2392

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE B2 (CONTINUED)



Appendix A CAPILLARY WATER ABSORPTION& TOTAL IMMERSION **SAMPLE B3**
TREATMENT: REMMERS KSE 300 E

W_{dry} (g)	W_{max} (g)	U_o (g) W_{max}-W_{dry}
310.7	318.2	7.5

Imbibition Capacity	% Apparent Porosity	% Open Porosity
0.024	2.4	6.0

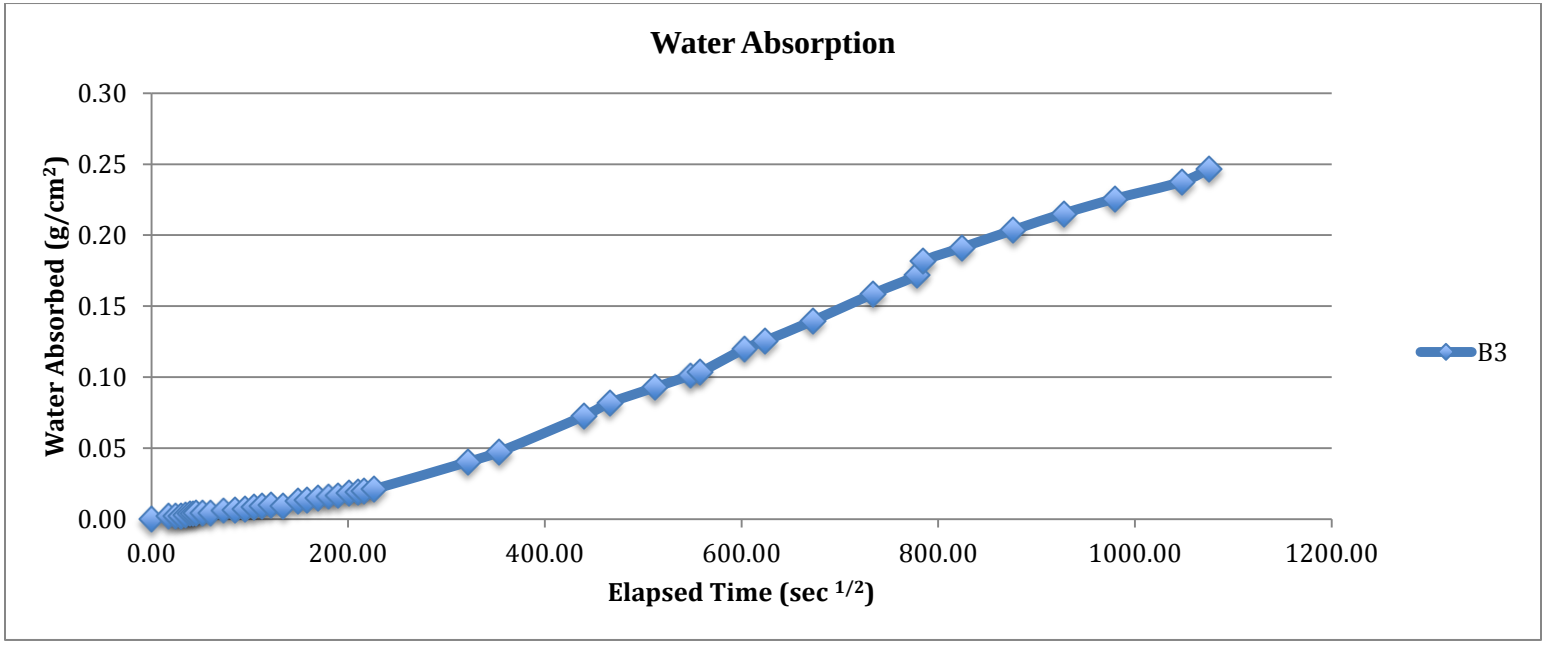
DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12	7:43 AM	0.00	0.00	310.68	0.00	0
4/13/12	7:48 AM	300.00	17.32	310.73	0.05	0.002
4/13/12	7:53 AM	600.00	24.49	310.73	0.05	0.002
4/13/12	7:58 AM	900.00	30.00	310.74	0.06	0.0024
4/13/12	8:03 AM	1200.00	34.64	310.76	0.08	0.0032
4/13/12	8:08 AM	1500.00	38.73	310.78	0.10	0.004
4/13/12	8:13 AM	1800.00	42.43	310.78	0.10	0.004
4/13/12	8:18 AM	2100.00	45.83	310.79	0.11	0.0044
4/13/12	8:28 AM	2700.00	51.96	310.79	0.11	0.0044
4/13/12	8:43 AM	3600.00	60.00	310.79	0.11	0.0044
4/13/12		5400.00	73.48	310.83	0.15	0.006
4/13/12		7200.00	84.85	310.85	0.17	0.0068
4/13/12		9000.00	94.87	310.86	0.18	0.0072
4/13/12		10800.00	103.92	310.89	0.21	0.0084
4/13/12		12600.00	112.25	310.91	0.23	0.0092
4/13/12		14700.00	121.24	310.93	0.25	0.01
4/13/12		18000.00	134.16	310.92	0.24	0.0096
4/13/12		22200.00	149.00	311.00	0.32	0.0128

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE B3 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12		25200.00	158.75	311.02	0.34	0.0136
4/13/12		28800.00	169.71	311.05	0.37	0.0148
4/13/12		32400.00	180.00	311.08	0.40	0.016
4/13/12		36000.00	189.74	311.10	0.42	0.0168
4/13/12		40440.00	201.10	311.14	0.46	0.0184
4/13/12		43980.00	209.71	311.16	0.48	0.0192
4/13/12		46800.00	216.33	311.18	0.50	0.02
4/13/12		51180.00	226.23	311.21	0.53	0.0212
4/14/12		103500.00	321.71	311.69	1.01	0.0404
4/14/12		125220.00	353.86	311.87	1.19	0.0476
4/15/12	1:29 PM	193500.00	439.89	312.50	1.82	0.0728
4/15/12	8:02 PM	217140.00	465.98	312.73	2.05	0.082
4/16/12	8:29 AM	261900.00	511.76	313.00	2.32	0.0928
4/16/12	7:10 PM	300360.00	548.05	313.21	2.53	0.1012
4/16/12	10:17 PM	311580.00	558.19	313.27	2.59	0.1036
4/17/12	12:45 PM	363660.00	603.04	313.68	3.00	0.12
4/17/12	7:50 PM	389160.00	623.83	313.82	3.14	0.1256
4/18/12	1:14 PM	451800.00	672.16	314.17	3.49	0.1396
4/19/12	1:17 PM	538380.00	733.74	314.65	3.97	0.1588
4/20/12	8:01 AM	605820.00	778.34	314.98	4.30	0.172
4/20/12	10:48 PM	615840.00	784.75	315.22	4.54	0.1816
4/21/12	4:15 PM	678660.00	823.81	315.46	4.78	0.1912

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE B3 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/22/12	5:06 PM	768120.00	876.42	315.77	5.09	0.2036
4/23/12	6:36 PM	859920.00	927.32	316.06	5.38	0.2152
4/24/12	10:13 PM	959340.00	979.46	316.32	5.64	0.2256
4/26/12	12:46 PM	1098120.00	1047.91	316.62	5.94	0.2376
4/27/12	4:55 AM	1156260.00	1075.30	316.85	6.17	0.2468



Appendix A CAPILLARY WATER ABSORPTION& TOTAL IMMERSION **SAMPLE C1**
TREATMENT: UNTREATED (CONTROL)

W_{dry} (g)	W_{max} (g)	U_o (g) W_{max}-W_{dry}
315.4	327.6	12.2

Imbibition Capacity	% Apparent Porosity	% Open Porosity
0.0387	3.87	9.76

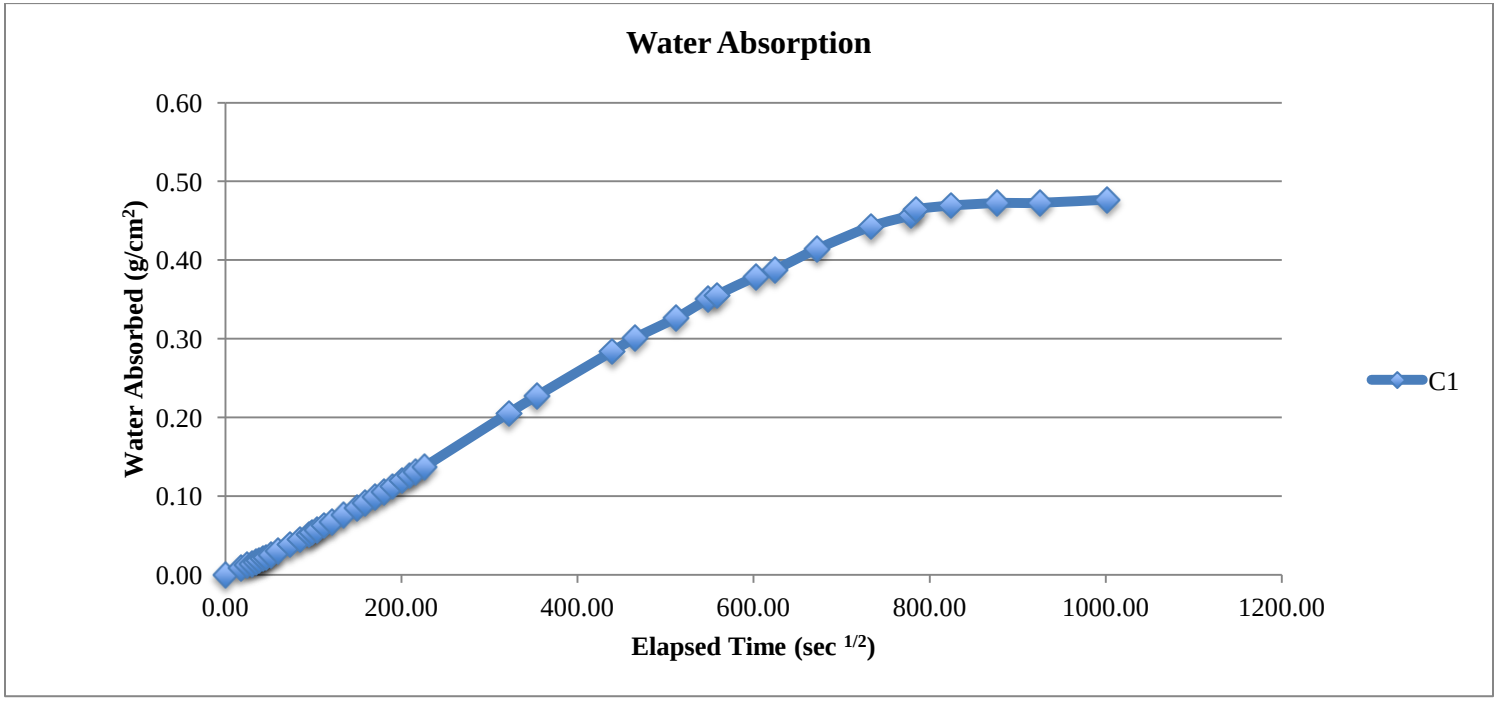
DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi ($g/cm^{2)}$
4/13/12		0.00	0.00	315.38	0.00	0.00
4/13/12		300.00	17.32	315.60	0.22	0.01
4/13/12		600.00	24.49	315.69	0.31	0.01
4/13/12		900.00	30.00	315.73	0.35	0.01
4/13/12		1200.00	34.64	315.80	0.42	0.02
4/13/12		1500.00	38.73	315.84	0.46	0.02
4/13/12		1800.00	42.43	315.90	0.52	0.02
4/13/12		2100.00	45.83	315.93	0.55	0.02
4/13/12		2700.00	51.96	316.01	0.63	0.03
4/13/12		3600.00	60.00	316.14	0.76	0.03
4/13/12		5400.00	73.48	316.34	0.96	0.04
4/13/12		7200.00	84.85	316.51	1.13	0.05
4/13/12		9000.00	94.87	316.67	1.29	0.05
4/13/12		9720.00	98.59	316.73	1.35	0.05
4/13/12		10800.00	103.92	316.81	1.43	0.06
4/13/12		12600.00	112.25	316.94	1.56	0.06
4/13/12		14700.00	121.24	317.06	1.68	0.07
4/13/12		18000.00	134.16	317.29	1.91	0.08

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE C1 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12		22200.00	149.00	317.51	2.13	0.09
4/13/12		25200.00	158.75	317.67	2.29	0.09
4/13/12		28800.00	169.71	317.86	2.48	0.10
4/13/12		32400.00	180.00	318.02	2.64	0.11
4/13/12		36000.00	189.74	318.19	2.81	0.11
4/13/12		40200.00	200.50	318.38	3.00	0.12
4/13/12		43740.00	209.14	318.54	3.16	0.13
4/13/12		46680.00	216.06	318.65	3.27	0.13
4/13/12		51120.00	226.10	318.81	3.43	0.14
4/14/12		103440.00	321.62	320.51	5.13	0.21
4/14/12		125220.00	353.86	321.06	5.68	0.23
4/15/12	1:27 PM	193320.00	439.68	322.48	7.10	0.28
4/15/12	8:04 PM	217020.00	465.85	322.91	7.53	0.30
4/16/12	8:30 AM	261900.00	511.76	323.54	8.16	0.33
4/16/12	7:12 PM	300420.00	548.11	324.14	8.76	0.35
4/17/12	10:20 PM	311700.00	558.30	324.27	8.89	0.36
4/17/12	12:46 PM	363660.00	603.04	324.86	9.48	0.38
4/17/12	7:52 PM	389220.00	623.87	325.07	9.69	0.39
4/18/12	1:15 PM	451800.00	672.16	325.73	10.35	0.41
4/19/12	1:17 PM	538380.00	733.74	326.45	11.07	0.44
4/20/12	8:00 AM	605700.00	778.27	326.80	11.42	0.46
4/20/12	10:49 PM	615840.00	784.75	326.99	11.61	0.46

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE C1 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/21/12	4:16 PM	678660.00	823.81	327.11	11.73	0.47
4/22/12	5:05 PM	768000.00	876.36	327.19	11.81	0.47
4/23/12	6:37 PM	856320.00	925.38	327.20	11.82	0.47
4/24/12	10:14 PM	1002780.00	1001.39	327.30	11.92	0.48



Appendix A CAPILLARY WATER ABSORPTION& TOTAL IMMERSION **SAMPLE C2**
TREATMENT: UNTREATED (CONTROL)

W_{dry} (g)	W_{max} (g)	U_o (g) W_{max}-W_{dry}
293.4	306.6	13.2

Imbibition Capacity	% Apparent Porosity	% Open Porosity
0.0450	4.50	10.6

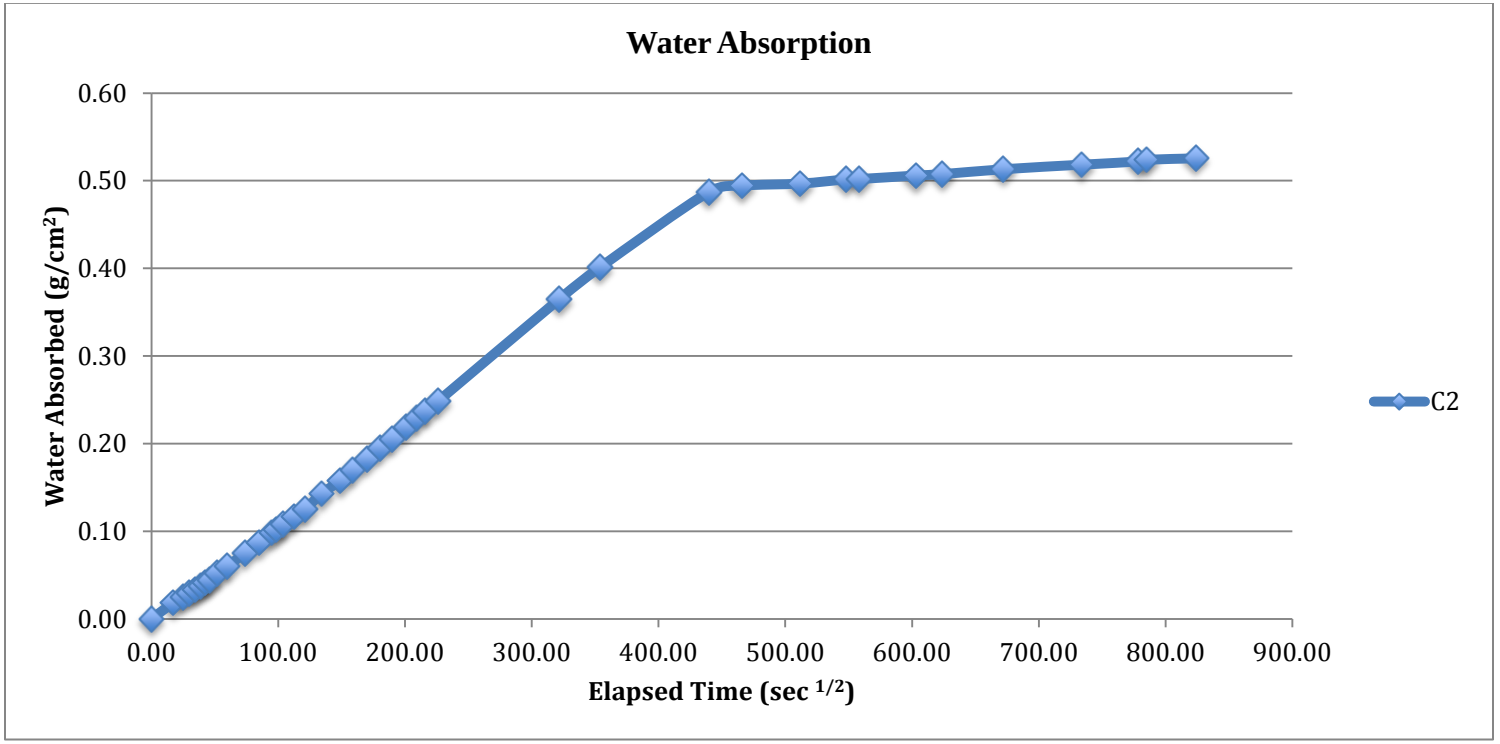
DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME (SEC $^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12		0.00	0.00	293.44	0.00	0.00
4/13/12		300.00	17.32	293.90	0.46	0.02
4/13/12		600.00	24.49	294.06	0.62	0.02
4/13/12		900.00	30.00	294.18	0.74	0.03
4/13/12		1200.00	34.64	294.27	0.83	0.03
4/13/12		1500.00	38.73	294.38	0.94	0.04
4/13/12		1800.00	42.43	294.48	1.04	0.04
4/13/12		2100.00	45.83	294.55	1.11	0.04
4/13/12		2700.00	51.96	294.74	1.30	0.05
4/13/12		3600.00	60.00	294.94	1.50	0.06
4/13/12		5400.00	73.48	295.31	1.87	0.07
4/13/12		7200.00	84.85	295.61	2.17	0.09
4/13/12		9000.00	94.87	295.90	2.46	0.10
4/13/12		9720.00	98.59	295.98	2.54	0.10
4/13/12		10800.00	103.92	296.14	2.70	0.11
4/13/12		12600.00	112.25	296.36	2.92	0.12
4/13/12		14700.00	121.24	296.57	3.13	0.13

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE C2 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12		18000.00	134.16	297.01	3.57	0.14
4/13/12		22200.00	149.00	297.38	3.94	0.16
4/13/12		25200.00	158.75	297.68	4.24	0.17
4/13/12		28800.00	169.71	298.00	4.56	0.18
4/13/12		32400.00	180.00	298.31	4.87	0.19
4/13/12		36000.00	189.74	298.57	5.13	0.21
4/13/12		40200.00	200.50	298.91	5.47	0.22
4/13/12		43740.00	209.14	299.17	5.73	0.23
4/13/12		46680.00	216.06	299.36	5.92	0.24
4/13/12		51120.00	226.10	299.65	6.21	0.25
4/14/12		103440.00	321.62	302.56	9.12	0.36
4/14/12		125220.00	353.86	303.47	10.03	0.40
4/15/12	1:27 PM	193320.00	439.68	305.62	12.18	0.49
4/15/12	8:04 PM	217020.00	465.85	305.80	12.36	0.49
4/16/12	8:30 AM	261900.00	511.76	305.86	12.42	0.50
4/16/12	7:12 PM	300420.00	548.11	305.98	12.54	0.50
4/17/12	10:20 PM	311700.00	558.30	305.99	12.55	0.50
4/17/12	12:46 PM	363660.00	603.04	306.09	12.65	0.51
4/17/12	7:52 PM	389220.00	623.87	306.13	12.69	0.51
4/18/12	1:15 PM	451800.00	672.16	306.27	12.83	0.51
4/19/12	1:17 PM	538380.00	733.74	306.40	12.96	0.52
4/20/12	8:00 AM	605700.00	778.27	306.49	13.05	0.52

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE C2 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/20/12	10:49 PM	615840.00	784.75	306.54	13.10	0.52
4/21/12	4:16 PM	678660.00	823.81	306.58	13.14	0.53



Appendix A CAPILLARY WATER ABSORPTION& TOTAL IMMERSION **SAMPLE C3**
TREATMENT: UNTREATED (CONTROL)

W_{dry} (g)	W_{max} (g)	U_o (g) W_{max}-W_{dry}
309.4	322.2	12.8

Imbibition Capacity	% Apparent Porosity	% Open Porosity
0.41	4.14	10.2

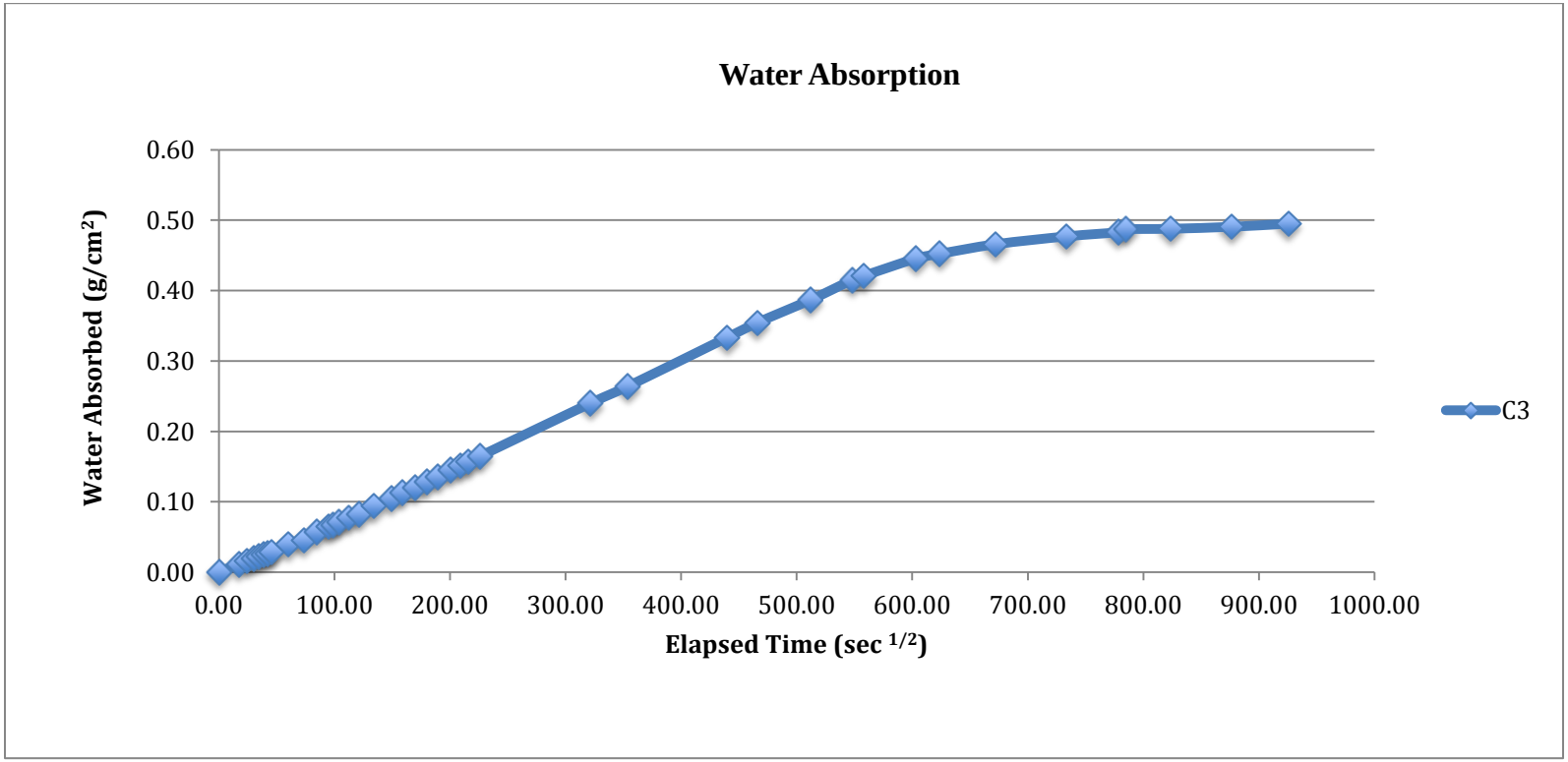
DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12		0.00	0.00	309.37	0.00	0.00
4/13/12		300.00	17.32	309.66	0.29	0.01
4/13/12		600.00	24.49	309.77	0.40	0.02
4/13/12		900.00	30.00	309.86	0.49	0.02
4/13/12		1200.00	34.64	309.93	0.56	0.02
4/13/12		1500.00	38.73	309.99	0.62	0.02
4/13/12		1800.00	42.43	310.04	0.67	0.03
4/13/12		2100.00	45.83	310.10	0.73	0.03
4/13/12		3600.00	60.00	310.36	0.99	0.04
4/13/12		5400.00	73.48	310.51	1.14	0.05
4/13/12		7200.00	84.85	310.80	1.43	0.06
4/13/12		9000.00	94.87	310.99	1.62	0.06
4/13/12		9720.00	98.59	311.06	1.69	0.07
4/13/12		10800.00	103.92	311.16	1.79	0.07
4/13/12		12600.00	112.25	311.30	1.93	0.08
4/13/12		14700.00	121.24	311.43	2.06	0.08
4/13/12		18000.00	134.16	311.73	2.36	0.09
4/13/12		22200.00	149.00	311.98	2.61	0.10

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE C3 (CONTINUED)

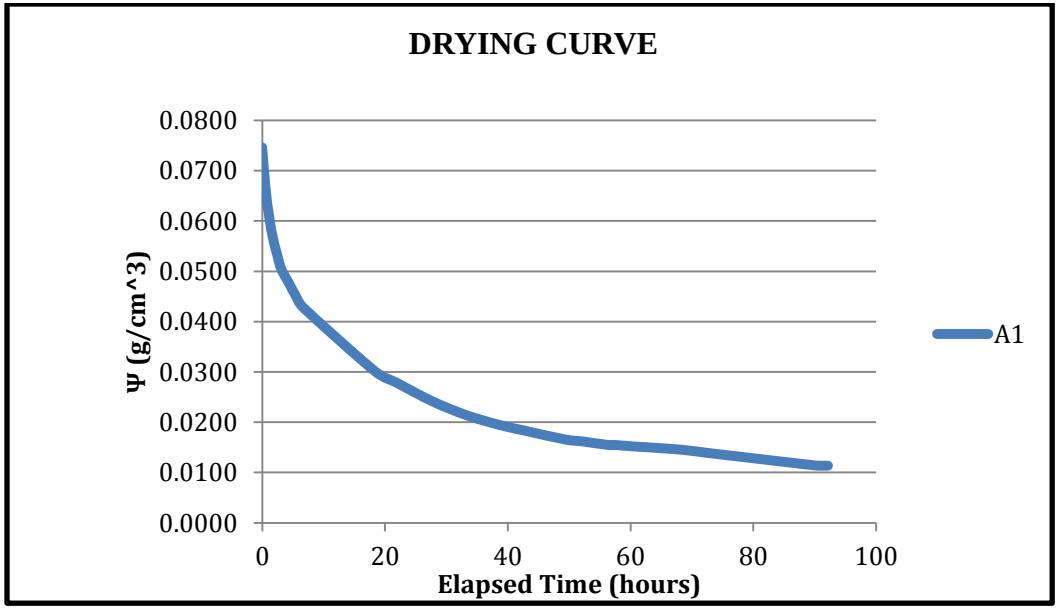
DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/13/12		25200.00	158.75	312.20	2.83	0.11
4/13/12		28800.00	169.71	312.38	3.01	0.12
4/13/12		32400.00	180.00	312.58	3.21	0.13
4/13/12		36000.00	189.74	312.76	3.39	0.14
4/13/12		40200.00	200.50	313.00	3.63	0.15
4/13/12		43740.00	209.14	313.16	3.79	0.15
4/13/12		46680.00	216.06	313.30	3.93	0.16
4/13/12		51120.00	226.10	313.49	4.12	0.16
4/14/12		103440.00	321.62	315.37	6.00	0.24
4/14/12		125220.00	353.86	315.97	6.60	0.26
4/15/12	1:27 PM	193320.00	439.68	317.70	8.33	0.33
4/15/12	8:04 PM	217020.00	465.85	318.23	8.86	0.35
4/16/12	8:30 AM	261900.00	511.76	319.04	9.67	0.39
4/16/12	7:12 PM	300420.00	548.11	319.75	10.38	0.42
4/17/12	10:20 PM	311700.00	558.30	319.90	10.53	0.42
4/17/12	12:46 PM	363660.00	603.04	320.51	11.14	0.45
4/17/12	7:52 PM	389220.00	623.87	320.68	11.31	0.45
4/18/12	1:15 PM	451800.00	672.16	321.02	11.65	0.47
4/19/12	1:17 PM	538380.00	733.74	321.30	11.93	0.48
4/20/12	8:00 AM	605700.00	778.27	321.45	12.08	0.48
4/20/12	10:49 PM	615840.00	784.75	321.55	12.18	0.49
4/21/12	4:16 PM	678660.00	823.81	321.57	12.20	0.49

APPENDIX A: CAPILLARY WATER ABSORPTION, SAMPLE C3 (CONTINUED)

DATE	TIME OF MEASUREMENT	CUMULATIVE TIME (SECONDS)	SQUARE ROOT OF TIME ($SEC^{O.5}$)	Wt (g)	Ut (g)	Mi (g/cm^2)
4/22/12	5:05 PM	768000.00	876.36	321.64	12.27	0.49
4/23/12	5:37 PM	856320.00	925.38	321.75	12.38	0.50



Appendix B DRYING **SAMPLE A1 (incomplete)**
TREATMENT: PROSOCO OH100



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
-0.0137	-0.998	-0.000155	-0.986	0.85	2.66

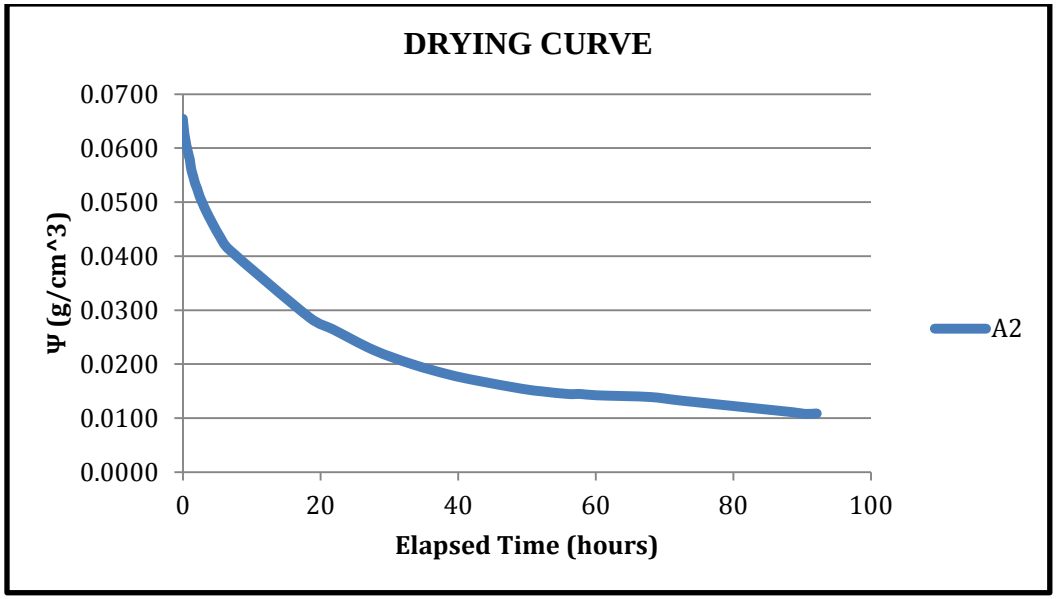
APPENDIX B: DRYING CURVE DATA, SAMPLE A1 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/28/12	0	0	306.5	9.3	0.0746	-0.0137
4/28/12	0.033333333	2	306.5	9.3	0.0740	-0.0137
4/28/12	0.066666667	4	306.4	9.2	0.0735	-0.0137
4/28/12	0.1	6	306.3	9.1	0.0730	-0.0137
4/28/12	0.133333333	8	306.3	9.1	0.0724	-0.0137
4/28/12	0.166666667	10	306.2	9.0	0.0719	-0.0137
4/28/12	0.2	12	306.1	8.9	0.0714	-0.0137
4/28/12	0.233333333	14	306.1	8.9	0.0710	-0.0137
4/28/12	0.266666667	16	306.0	8.8	0.0704	-0.0137
4/28/12	0.333333333	20	305.9	8.7	0.0694	-0.0137
4/28/12	0.466666667	28	305.7	8.4	0.0676	-0.0137
4/28/12	0.5	30	305.6	8.4	0.0670	-0.0137
4/28/12	0.583333333	35	305.5	8.3	0.0662	-0.0137
4/28/12	0.666666667	40	305.3	8.1	0.0651	-0.0137
4/28/12	0.75	45	305.2	8.0	0.0642	-0.0137
4/28/12	0.833333333	50	305.1	7.9	0.0633	-0.0137
4/28/12	0.916666667	55	305.0	7.8	0.0626	-0.00768
4/28/12	1	60	305.0	7.8	0.0620	-0.00816
4/28/12	1.166666667	70	304.8	7.6	0.0606	-0.00816
4/28/12	1.333333333	80	304.6	7.4	0.0593	-0.00720
4/28/12	1.5	90	304.5	7.3	0.0581	-0.00576
4/28/12	1.666666667	100	304.3	7.1	0.0571	-0.00576

APPENDIX B: DRYING CURVE DATA, SAMPLE A1 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/28/12	1.833333333	110	304.2	7.0	0.0562	-0.00512
4/28/12	2.45	147	303.9	6.7	0.0533	-0.00480
4/28/12	2.883333333	173	303.6	6.4	0.0512	-0.00302
4/28/12	3.333333333	200	303.4	6.2	0.0498	-0.00214
4/28/12	4.266666667	256	303.2	6.0	0.0478	-0.00227
4/28/12	5.466666667	328	302.8	5.6	0.0451	-0.00191
4/28/12	6.683333333	401	302.6	5.4	0.0428	-0.00108
4/29/12	18.41666667	1105	301.0	3.8	0.0301	-0.00064
4/30/12	21.78333333	1307	300.7	3.5	0.0279	-0.00064
4/30/12	27.7	1662	300.2	3.0	0.0242	-0.00050
4/30/12	33.33333333	2000	299.9	2.7	0.0214	-0.00036
4/30/12	38.68333333	2321	299.6	2.4	0.0194	-0.000155
4/30/12	42.75	2565	299.5	2.3	0.0183	-0.000155
4/30/12	49.33333333	2960	299.3	2.1	0.0166	-0.000155
4/30/12	52.26666667	3136	299.2	2.0	0.0162	-0.000155
4/30/12	56	3360	299.1	1.9	0.0155	-0.000155
5/1/12	57.83333333	3470	299.1	1.9	0.0154	-0.000155
5/1/12	60.18333333	3611	299.1	1.9	0.0152	-0.000155
5/1/12	68.01666667	4081	299.0	1.8	0.0146	-0.000155
5/1/12	72.86666667	4372	298.9	1.7	0.0138	-0.000155
5/1/12	88.58333333	5315	298.7	1.4	0.0116	-0.000155
5/2/12	90.38333333	5423	298.6	1.4	0.0114	-0.000155
5/2/12	92.13333333	5528	298.6	1.4	0.0114	-0.000155

Appendix B DRYING **SAMPLE A2 (incomplete)**
TREATMENT: PROSOCO OH100



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
-0.0110	-0.996	-0.000107	-0.992	0.94	2.42

APPENDIX B: DRYING CURVE DATA, SAMPLE A2 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/28/12	0	0	326.7	8.2	0.0654	-0.011038961
4/28/12	0.033333333	2	326.6	8.1	0.0650	-0.011038961
4/28/12	0.066666667	4	326.6	8.1	0.0646	-0.011038961
4/28/12	0.1	6	326.5	8.0	0.0642	-0.011038961
4/28/12	0.133333333	8	326.5	8.0	0.0638	-0.011038961
4/28/12	0.166666667	10	326.4	7.9	0.0634	-0.011038961
4/28/12	0.2	12	326.4	7.9	0.0630	-0.011038961
4/28/12	0.233333333	14	326.3	7.8	0.0626	-0.011038961
4/28/12	0.266666667	16	326.3	7.8	0.0623	-0.011038961
4/28/12	0.333333333	20	326.2	7.7	0.0618	-0.011038961
4/28/12	0.466666667	28	326.1	7.6	0.0609	-0.00960
4/28/12	0.5	30	326.1	7.6	0.0606	-0.00480
4/28/12	0.583333333	35	326.0	7.5	0.0602	-0.00576
4/28/12	0.666666667	40	326.0	7.5	0.0597	-0.00576
4/28/12	0.75	45	325.9	7.4	0.0592	-0.00480
4/28/12	0.833333333	50	325.9	7.4	0.0588	-0.00576
4/28/12	0.916666667	55	325.8	7.3	0.0583	-0.00384
4/28/12	1	60	325.8	7.3	0.0580	-0.00912
4/28/12	1.166666667	70	325.6	7.1	0.0565	-0.00576
4/28/12	1.333333333	80	325.4	6.9	0.0555	-0.00432
4/28/12	1.5	90	325.4	6.9	0.0548	-0.00480
4/28/12	1.666666667	100	325.3	6.8	0.0540	-0.00432

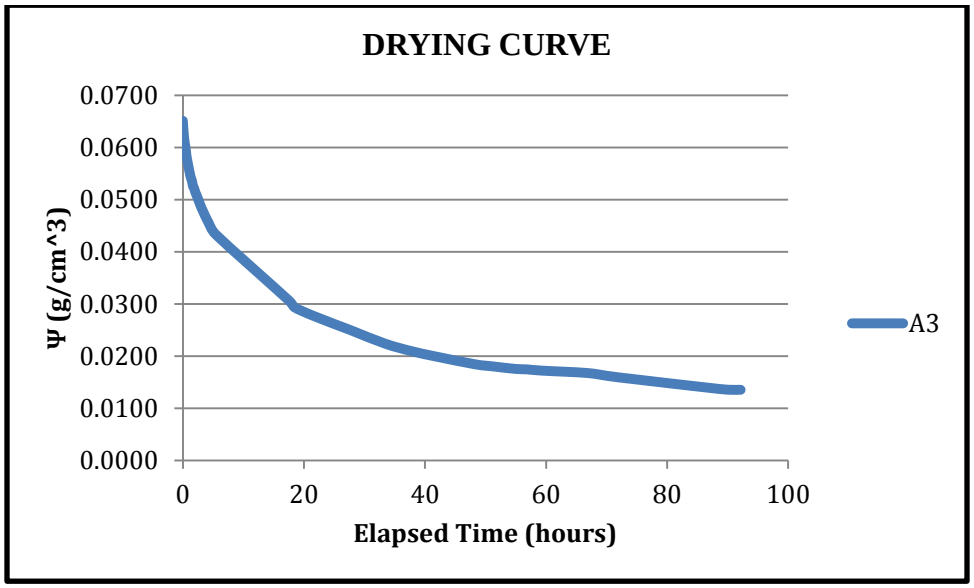
APPENDIX B: DRYING CURVE DATA, SAMPLE A2 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/28/12	1.833333333	110	325.2	6.7	0.0533	-0.00320
4/28/12	2.083333333	125	325.1	6.6	0.0525	-0.00393
4/28/12	2.45	147	324.9	6.4	0.0510	-0.00295
4/28/12	2.883333333	173	324.7	6.2	0.0498	-0.00284
4/28/12	3.333333333	200	324.6	6.1	0.0485	-0.00249
4/28/12	4.266666667	256	324.3	5.8	0.0462	-0.00227
4/28/12	5.466666667	328	323.9	5.4	0.0434	-0.00178
4/28/12	6.683333333	401	323.7	5.2	0.0413	-0.00108
4/29/12	18.41666667	1105	322.1	3.6	0.0286	-0.00064
4/30/12	21.78333333	1307	321.8	3.3	0.0265	-0.00065
4/30/12	27.7	1662	321.3	2.8	0.0226	-0.00047
4/30/12	33.33333333	2000	321.0	2.5	0.0200	-0.00036
4/30/12	38.68333333	2321	320.8	2.3	0.0181	-0.00028
4/30/12	42.75	2565	320.6	2.1	0.0170	-0.00023
4/30/12	49.33333333	2960	320.4	1.9	0.0154	-0.0000835
4/30/12	52.26666667	3136	320.4	1.9	0.0150	-0.0000835
4/30/12	56	3360	320.3	1.8	0.0145	-0.0000835
5/1/12	57.83333333	3470	320.3	1.8	0.0145	-0.0000835
5/1/12	60.18333333	3611	320.3	1.8	0.0142	-0.0000835
5/1/12	68.01666667	4081	320.2	1.7	0.0139	-0.0000835
5/1/12	72.86666667	4372	320.2	1.6	0.0132	-0.0000835
5/1/12	88.58333333	5315	319.9	1.4	0.0111	-0.0000835

APPENDIX B: DRYING CURVE DATA, SAMPLE A2 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/2/12	90.38333333	5423	319.9	1.4	0.0108	-0.0000835
5/2/12	92.13333333	5528	319.9	1.4	0.0109	-0.0000835

Appendix B DRYING **SAMPLE A3 (incomplete)**
TREATMENT: PROSOCO OH100



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
-0.0152	-0.996	-0.000126	-0.988	1.1	2.63

APPENDIX B: DRYING CURVE DATA, SAMPLE A3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/28/12	0	0	315.7	8.1	0.0651	-0.0152
4/28/12	0.033333333	2	315.7	8.1	0.0645	-0.0152
4/28/12	0.066666667	4	315.6	8.0	0.0639	-0.0152
4/28/12	0.1	6	315.5	7.9	0.0634	-0.0152
4/28/12	0.133333333	8	315.5	7.8	0.0628	-0.0152
4/28/12	0.166666667	10	315.4	7.8	0.0624	-0.0152
4/28/12	0.2	12	315.3	7.7	0.0619	-0.0152
4/28/12	0.233333333	14	315.3	7.7	0.0616	-0.0152
4/28/12	0.266666667	16	315.3	7.7	0.0613	-0.00840
4/28/12	0.333333333	20	315.2	7.6	0.0607	-0.00780
4/28/12	0.466666667	28	315.1	7.5	0.0597	-0.00720
4/28/12	0.5	30	315.0	7.4	0.0594	-0.01056
4/28/12	0.583333333	35	314.9	7.3	0.0586	-0.00768
4/28/12	0.666666667	40	314.8	7.2	0.0579	-0.00576
4/28/12	0.75	45	314.8	7.2	0.0574	-0.00672
4/28/12	0.833333333	50	314.7	7.1	0.0569	-0.00576
4/28/12	0.916666667	55	314.7	7.0	0.0564	-0.00576
4/28/12	1	60	314.6	7.0	0.0559	-0.00576
4/28/12	1.166666667	70	314.5	6.9	0.0550	-0.00480
4/28/12	1.333333333	80	314.4	6.8	0.0542	-0.00336
4/28/12	1.5	90	314.3	6.7	0.0536	-0.00576
4/28/12	1.666666667	100	314.2	6.6	0.0526	-0.00240

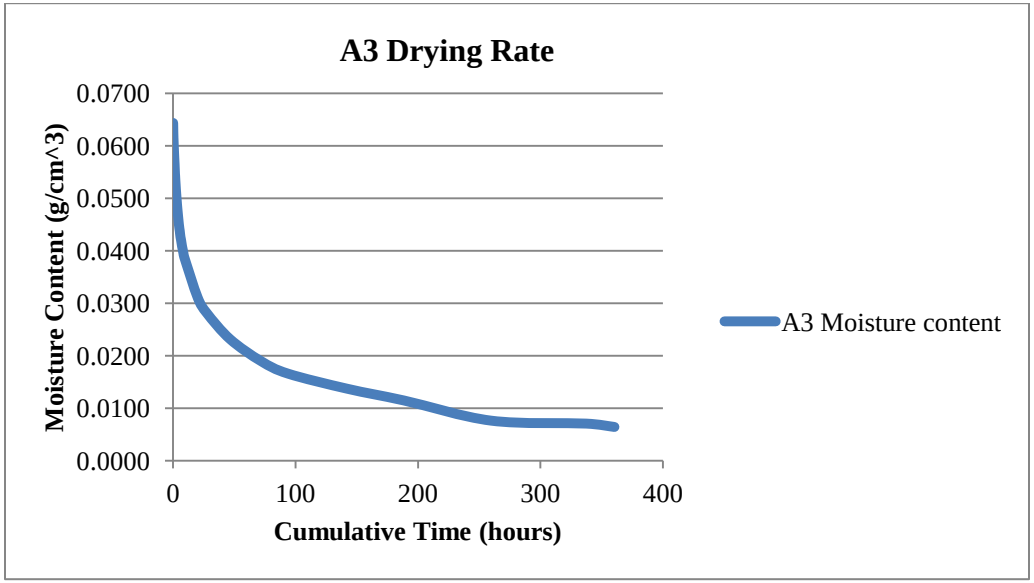
APPENDIX B: DRYING CURVE DATA, SAMPLE A3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/28/12	1.833333333	110	314.1	6.5	0.0522	-0.00352
4/28/12	2.083333333	125	314.0	6.4	0.0514	-0.00284
4/28/12	2.45	147	313.9	6.3	0.0503	-0.00314
4/28/12	2.883333333	173	313.7	6.1	0.0490	-0.00267
4/28/12	3.333333333	200	313.6	6.0	0.0478	-0.00240
4/28/12	4.266666667	256	313.3	5.7	0.0455	-0.00187
4/28/12	5.466666667	328	313.0	5.4	0.0433	-0.00105
4/28/12	17.51666667	1051	311.4	3.8	0.0306	-0.00142
4/29/12	18.41666667	1105	311.3	3.7	0.0294	-0.00052
4/30/12	21.78333333	1307	311.1	3.4	0.0276	-0.00045
4/30/12	27.7	1662	310.7	3.1	0.0250	-0.00045
4/30/12	33.33333333	2000	310.4	2.8	0.0224	-0.00033
4/30/12	37.66666667	2260	310.2	2.6	0.0210	-0.000136958
4/30/12	41.71666667	2503	310.1	2.5	0.0199	-0.000136958
4/30/12	48.31666667	2899	309.9	2.3	0.0184	-0.000136958
4/30/12	51.25	3075	309.9	2.3	0.0180	-0.000136958
4/30/12	54.96666667	3298	309.8	2.2	0.0175	-0.000136958
5/1/12	56.8	3408	309.8	2.2	0.0174	-0.000136958
5/1/12	59.18333333	3551	309.8	2.1	0.0172	-0.000136958
5/1/12	66.98333333	4019	309.7	2.1	0.0167	-0.000136958
5/1/12	71.85	4311	309.6	2.0	0.0159	-0.000136958
5/1/12	88.58333333	5315	309.3	1.7	0.0137	-0.000136958

APPENDIX B: DRYING CURVE DATA, SAMPLE A3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/2/12	90.38333333	5423	309.3	1.7	0.0135	-0.000136958
5/2/12	92.13333333	5528	309.3	1.7	0.0135	-0.000136958

Appendix B DRYING: SECOND TRIAL **SAMPLE A3 (complete)**
TREATMENT: PROSOCO OH100



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
DATE	-9.90E-01	-1.07E-05	-0.942	0.83	2.15

APPENDIX B: DRYING CURVE DATA, SAMPLE A3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/21/12	0	0	315.6	8.0	0.0643	-0.0120
5/21/12	0.033333333	2	315.6	8.0	0.0639	-0.0072
5/21/12	0.066666667	4	315.6	8.0	0.0637	-0.0192
5/21/12	0.1	6	315.5	7.9	0.0630	-0.0096
5/21/12	0.133333333	8	315.4	7.8	0.0627	-0.0144
5/21/12	0.166666667	10	315.4	7.8	0.0622	-0.0048
5/21/12	0.2	12	315.4	7.8	0.0621	-0.0096
5/21/12	0.266666667	16	315.3	7.7	0.0614	-0.0048
5/21/12	0.3	18	315.3	7.7	0.0613	-0.0064
5/21/12	0.35	21	315.2	7.6	0.0610	-0.0067
5/21/12	0.433333333	26	315.2	7.5	0.0604	-0.0064
5/21/12	0.483333333	29	315.1	7.5	0.0601	-0.0060
5/21/12	0.55	33	315.1	7.5	0.0597	-0.0056
5/21/12	0.65	39	315.0	7.4	0.0591	-0.0048
5/21/12	0.7	42	315.0	7.4	0.0589	-0.0060
5/21/12	0.766666667	46	314.9	7.3	0.0585	-0.0048
5/21/12	0.833333333	50	314.9	7.3	0.0582	-0.0053
5/21/12	1	60	314.8	7.2	0.0573	-0.0048
5/21/12	1.166666667	70	314.7	7.1	0.0565	-0.0058
5/21/12	1.5	90	314.4	6.8	0.0546	-0.0029
5/21/12	1.583333333	95	314.4	6.8	0.0543	-0.0042
5/21/12	1.833333333	110	314.3	6.7	0.0533	-0.0038

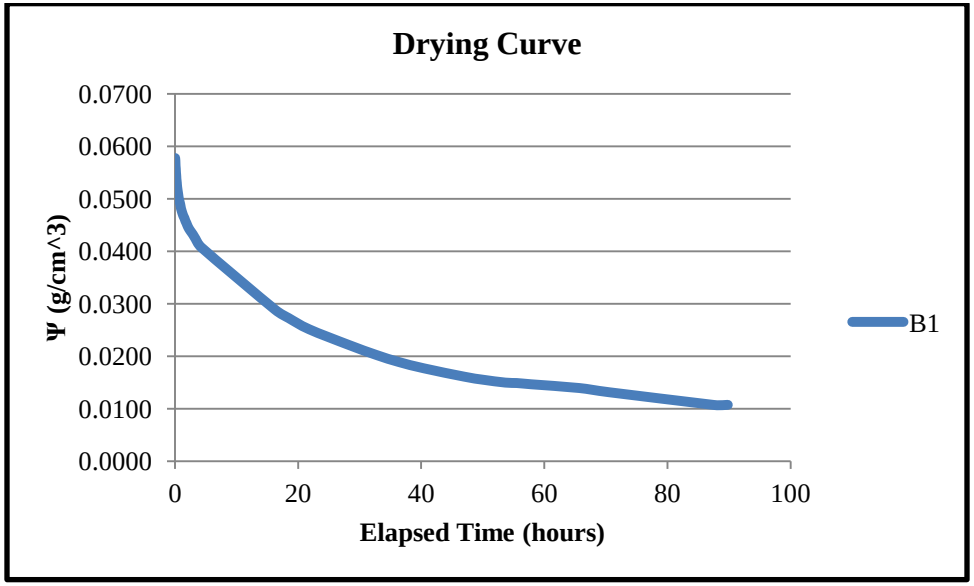
APPENDIX B: DRYING CURVE DATA, SAMPLE A3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/21/12	2	120	314.2	6.6	0.0526	-0.0038
5/21/12	2.25	135	314.1	6.5	0.0517	-0.0035
5/21/12	2.433333333	146	314.0	6.4	0.0510	-0.0031
5/21/12	2.666666667	160	313.9	6.3	0.0503	-0.0031
5/21/12	3.05	183	313.7	6.1	0.0491	-0.0028
5/21/12	3.45	207	313.6	6.0	0.0480	-0.0025
5/21/12	4.65	279	313.2	5.6	0.0450	-0.0018
5/21/12	5.333333333	320	313.1	5.5	0.0438	-0.0020
5/21/12	5.533333333	332	313.0	5.4	0.0434	-0.0020
5/21/12	5.933333333	356	312.9	5.3	0.0426	-0.0012
5/21/12	6.266666667	376	312.9	5.3	0.0422	-0.0014
5/21/12	6.616666667	397	312.8	5.2	0.0418	-0.0015
5/21/12	7.216666667	433	312.7	5.1	0.0409	-0.0012
5/21/12	7.766666667	466	312.6	5.0	0.0402	-0.0012
5/21/12	8.433333333	506	312.5	4.9	0.0394	-0.0011
5/21/12	9	540	312.5	4.8	0.0388	-0.0007
5/21/12	20.03333333	1202	311.5	3.9	0.0310	-0.0004
5/22/12	27.53333333	1652	311.1	3.5	0.0281	-0.0003
5/23/12	46.51666667	2791	310.5	2.9	0.0231	-0.0002
5/24/12	71.63333333	4298	310.0	2.4	0.0190	-0.0001
5/25/12	93.73333333	5624	309.7	2.1	0.0166	-0.0001
5/27/12	142.1666667	8530	309.3	1.7	0.0137	0.0000

APPENDIX B: DRYING CURVE DATA, SAMPLE A3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/29/12	188.5166667	11311	309.0	1.4	0.0114	-0.0001
6/1/12	259.7166667	15583	308.6	0.9	0.0076	0.0000
6/4/12	337.2833333	20237	308.5	0.9	0.0070	0.0000
6/5/12	360.3	21618	308.4	0.8	0.0064	0.0000

Appendix B DRYING **SAMPLE B1 (incomplete)**
TREATMENT: REMMERS KSE 300 E



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
-0.0190	-0.995	-0.000166	-0.970	1.1	2.39

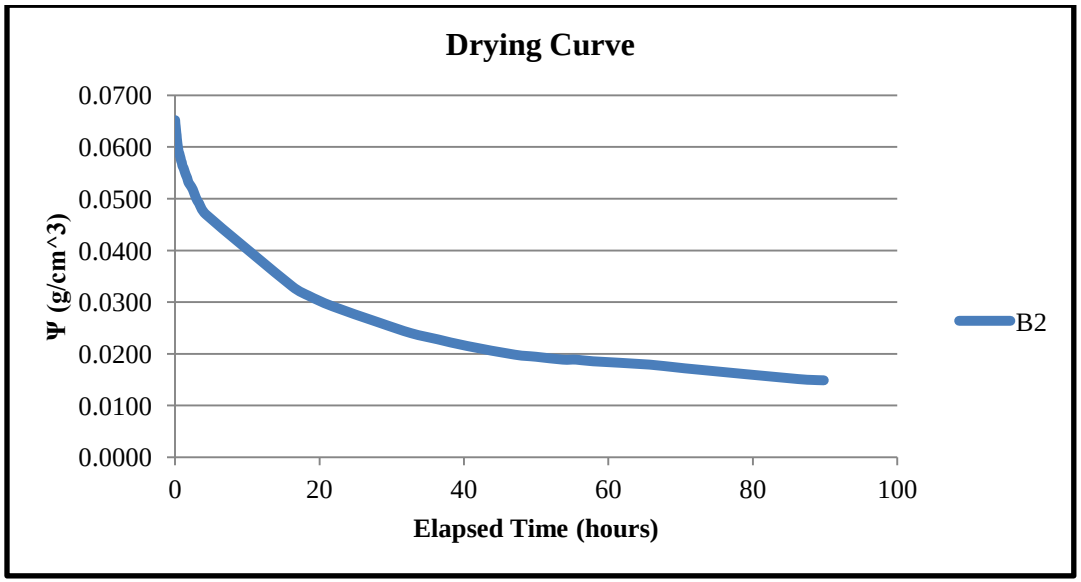
APPENDIX B: DRYING CURVE DATA, SAMPLE B1 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/28/12	0	0	308.8	7.2	0.0578	-0.019028571
4/28/12	0.033333333	2	308.8	7.2	0.0573	-0.019028571
4/28/12	0.066666667	4	308.6	7.0	0.0562	-0.019028571
4/28/12	0.1	6	308.6	7.0	0.0558	-0.019028571
4/28/12	0.133333333	8	308.5	6.9	0.0550	-0.019028571
4/28/12	0.166666667	10	308.4	6.8	0.0546	-0.019028571
4/28/12	0.2	12	308.3	6.7	0.0538	-0.019028571
4/28/12	0.233333333	14	308.3	6.7	0.0534	-0.019028571
4/28/12	0.266666667	16	308.2	6.6	0.0530	-0.0132
4/28/12	0.333333333	20	308.1	6.5	0.0522	-0.0084
4/28/12	0.466666667	28	308.0	6.4	0.0510	-0.0072
4/28/12	0.5	30	308.0	6.3	0.0508	-0.0086
4/28/12	0.583333333	35	307.9	6.3	0.0501	-0.0048
4/28/12	0.666666667	40	307.8	6.2	0.0497	-0.0048
4/28/12	0.75	45	307.8	6.2	0.0493	-0.0048
4/28/12	0.833333333	50	307.7	6.1	0.0489	-0.0067
4/28/12	0.916666667	55	307.6	6.0	0.0483	-0.0048
4/28/12	1	60	307.6	6.0	0.0479	-0.0038
4/28/12	1.166666667	70	307.5	5.9	0.0473	-0.0034
4/28/12	1.333333333	80	307.4	5.8	0.0467	-0.0024
4/28/12	1.5	90	307.4	5.8	0.0463	-0.0034
4/28/12	1.666666667	100	307.3	5.7	0.0458	-0.0024

APPENDIX B: DRYING CURVE DATA, SAMPLE B1 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/28/12	1.833333333	110	307.3	5.7	0.0454	-0.0029
4/28/12	2.083333333	125	307.2	5.6	0.0446	-0.0020
4/28/12	2.45	147	307.1	5.5	0.0439	-0.0017
4/28/12	2.883333333	173	307.0	5.4	0.0432	-0.0020
4/28/12	3.333333333	200	306.9	5.3	0.0423	-0.0017
4/28/12	4.266666667	256	306.7	5.1	0.0407	-0.0010
4/28/12	16.21666667	973	305.2	3.6	0.0289	-0.0007
4/28/12	18.41666667	1105	305.0	3.4	0.0273	-0.0006
4/28/12	21.78333333	1307	304.7	3.1	0.0251	-0.0005
4/29/12	28.16666667	1690	304.4	2.8	0.0222	-0.000166
4/29/12	32.66666667	1960	304.1	2.5	0.0202	-0.000166
4/29/12	36.36666667	2182	304.0	2.4	0.0189	-0.000166
4/30/12	40.43333333	2426	303.8	2.2	0.0177	-0.000166
4/30/12	47.01666667	2821	303.6	2.0	0.0161	-0.000166
4/30/12	49.95	2997	303.5	1.9	0.0155	-0.000166
4/30/12	53.66666667	3220	303.5	1.9	0.0150	-0.000166
4/30/12	55.5	3330	303.5	1.9	0.0149	-0.000166
5/1/12	57.86666667	3472	303.4	1.8	0.0146	-0.000166
5/1/12	65.7	3942	303.3	1.7	0.0139	-0.000166
5/1/12	70.55	4233	303.2	1.6	0.0131	-0.000166
5/2/12	86.26666667	5176	303.0	1.4	0.0109	-0.000166
5/2/12	88.06666667	5284	302.9	1.3	0.0106	-0.000166
5/2/12	89.81666667	5389	302.9	1.3	0.0107	-0.000166

Appendix B DRYING **SAMPLE B2 (incomplete)**
TREATMENT: REMMERS KSE 300 E



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
-0.0129	-0.995	-0.000117	-0.998	1.1	2.63

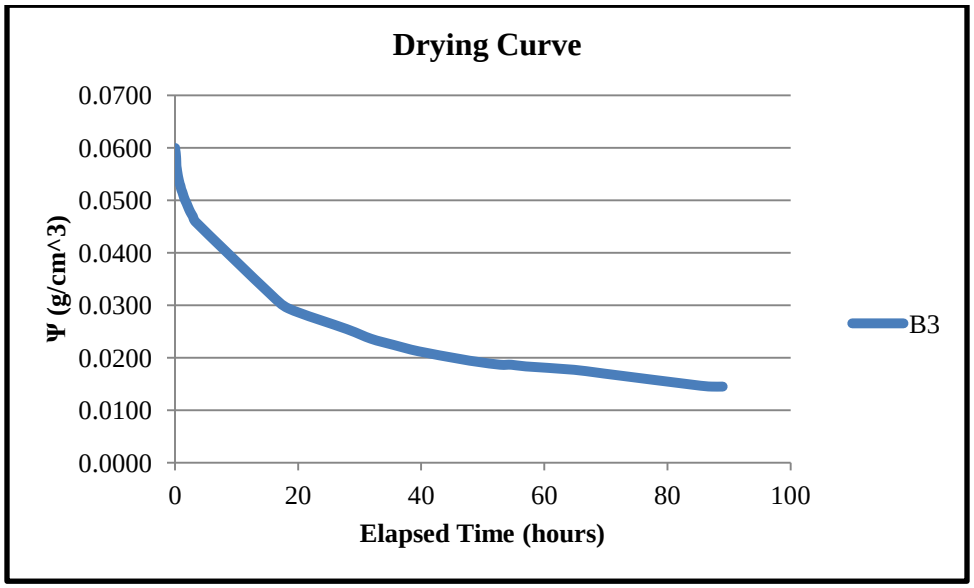
APPENDIX B: DRYING CURVE DATA, SAMPLE B2 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/28/12	0	0	319.4	8.2	0.0652	-0.0129
4/28/12	0.033333333	2	319.3	8.1	0.0645	-0.0129
4/28/12	0.066666667	4	319.2	8.0	0.0641	-0.0129
4/28/12	0.1	6	319.2	7.9	0.0636	-0.0129
4/28/12	0.133333333	8	319.1	7.9	0.0631	-0.0129
4/28/12	0.166666667	10	319.0	7.8	0.0626	-0.0129
4/28/12	0.2	12	319.0	7.8	0.0623	-0.0129
4/28/12	0.233333333	14	318.9	7.7	0.0617	-0.0129
4/28/12	0.266666667	16	318.9	7.7	0.0613	-0.0129
4/28/12	0.333333333	20	318.8	7.6	0.0605	-0.0129
4/28/12	0.466666667	28	318.6	7.4	0.0592	-0.0129
4/28/12	0.5	30	318.6	7.4	0.0590	-0.00384
4/28/12	0.583333333	35	318.5	7.3	0.0587	-0.00576
4/28/12	0.666666667	40	318.5	7.3	0.0582	-0.00480
4/28/12	0.75	45	318.4	7.2	0.0578	-0.00672
4/28/12	0.833333333	50	318.4	7.2	0.0573	-0.00288
4/28/12	0.916666667	55	318.3	7.1	0.0570	-0.00768
4/28/12	1	60	318.3	7.1	0.0564	-0.00288
4/28/12	1.166666667	70	318.2	7.0	0.0559	-0.00432
4/28/12	1.333333333	80	318.1	6.9	0.0552	-0.00384
4/28/12	1.5	90	318.0	6.8	0.0546	-0.00336
4/28/12	1.666666667	100	318.0	6.8	0.0540	-0.00480

APPENDIX B: DRYING CURVE DATA, SAMPLE B2 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/28/12	1.833333333	110	317.9	6.7	0.0532	-0.00224
4/28/12	2.083333333	125	317.8	6.6	0.0526	-0.00240
4/28/12	2.45	147	317.7	6.5	0.0518	-0.00369
4/28/12	2.883333333	173	317.5	6.3	0.0502	-0.00249
4/28/12	3.333333333	200	317.3	6.1	0.0490	-0.00223
4/28/12	4.266666667	256	317.1	5.9	0.0470	-0.00116
4/28/12	16.21666667	973	315.3	4.1	0.0330	-0.00080
4/29/12	18.41666667	1105	315.1	3.9	0.0313	-0.00062
4/29/12	21.78333333	1307	314.9	3.7	0.0292	-0.000231163
4/29/12	28.16666667	1690	314.5	3.3	0.0261	-0.000231163
4/30/12	32.66666667	1960	314.2	3.0	0.0240	-0.000231163
4/30/12	36.36666667	2182	314.1	2.9	0.0228	-0.000231163
4/30/12	40.43333333	2426	313.9	2.7	0.0215	-0.000231163
4/30/12	47.01666667	2821	313.7	2.5	0.0198	-0.000231163
4/30/12	49.95	2997	313.6	2.4	0.0194	-0.000231163
5/1/12	53.66666667	3220	313.6	2.4	0.0189	-0.000231163
5/1/12	55.5	3330	313.6	2.4	0.0189	-0.000231163
5/1/12	57.86666667	3472	313.5	2.3	0.0186	-0.000231163
5/1/12	65.7	3942	313.4	2.2	0.0179	-0.000231163
5/1/12	70.55	4233	313.4	2.2	0.0172	-0.000231163
5/2/12	86.26666667	5176	313.1	1.9	0.0151	-0.000231163
5/2/12	88.06666667	5284	313.1	1.9	0.0150	-0.000231163
5/2/12	89.81666667	5389	313.1	1.9	0.0149	-0.000231163

Appendix B DRYING **SAMPLE B3 (incomplete)**
TREATMENT: REMMERS KSE 300 E



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
-0.0148	-0.983	-0.000182	-0.954	1.1	2.41

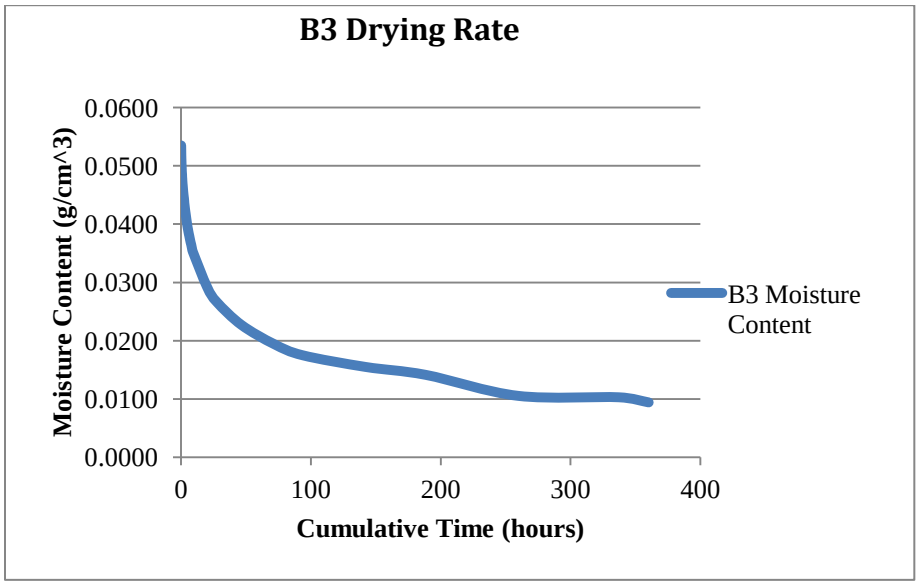
APPENDIX B: DRYING CURVE DATA, SAMPLE B3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/28/12	0	0	318.2	7.5	0.0599	-0.0148
4/28/12	0.033333333	2	318.1	7.4	0.0594	-0.0148
4/28/12	0.066666667	4	318.1	7.4	0.0592	-0.0148
4/28/12	0.1	6	318.1	7.4	0.0589	-0.0148
4/28/12	0.133333333	8	318.0	7.3	0.0584	-0.0148
4/28/12	0.166666667	10	317.9	7.2	0.0579	-0.0148
4/28/12	0.2	12	317.8	7.1	0.0566	-0.0148
4/28/12	0.233333333	14	317.7	7.0	0.0562	-0.0148
4/28/12	0.266666667	16	317.7	7.0	0.0560	-0.0148
4/28/12	0.333333333	20	317.6	6.9	0.0554	-0.0148
4/28/12	0.466666667	28	317.5	6.8	0.0545	-0.00480
4/28/12	0.5	30	317.5	6.8	0.0543	-0.00576
4/28/12	0.583333333	35	317.4	6.7	0.0538	-0.00480
4/28/12	0.666666667	40	317.4	6.7	0.0534	-0.00480
4/28/12	0.75	45	317.3	6.6	0.0530	-0.00288
4/28/12	0.833333333	50	317.3	6.6	0.0528	-0.00480
4/28/12	0.916666667	55	317.3	6.6	0.0524	-0.00480
4/28/12	1	60	317.2	6.5	0.0520	-0.00288
4/28/12	1.166666667	70	317.1	6.4	0.0515	-0.00384
4/28/12	1.333333333	80	317.1	6.4	0.0509	-0.00336
4/28/12	1.5	90	317.0	6.3	0.0503	-0.00288
4/28/12	1.666666667	100	316.9	6.2	0.0498	-0.00240

APPENDIX B: DRYING CURVE DATA, SAMPLE B3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/28/12	1.833333333	110	316.9	6.2	0.0494	-0.00288
4/28/12	2.083333333	125	316.8	6.1	0.0487	-0.00262
4/28/12	2.45	147	316.7	6.0	0.0478	-0.00203
4/28/12	2.883333333	173	316.6	5.9	0.0469	-0.00231
4/28/12	3.333333333	200	316.4	5.7	0.0458	-0.00113
4/28/12	15.35	921	314.7	4.0	0.0322	-0.00094
4/29/12	18.41666667	1105	314.4	3.7	0.0294	-0.000228
4/29/12	27.86666667	1672	313.9	3.2	0.0254	-0.000228
4/30/12	31.8	1908	313.7	2.9	0.0236	-0.000228
4/30/12	35.53333333	2132	313.5	2.8	0.0224	-0.000228
4/30/12	39.56666667	2374	313.4	2.7	0.0212	-0.000228
4/30/12	46.16666667	2770	313.2	2.5	0.0198	-0.000228
4/30/12	49.1	2946	313.1	2.4	0.0192	-0.000228
5/1/12	52.81666667	3169	313.0	2.3	0.0186	-0.000228
5/1/12	54.65	3279	313.0	2.3	0.0186	-0.000228
5/1/12	57	3420	313.0	2.3	0.0183	-0.000228
5/1/12	64.83333333	3890	312.9	2.2	0.0177	-0.000228
5/1/12	69.68333333	4181	312.8	2.1	0.0170	-0.000228
5/2/12	85.4	5124	312.5	1.8	0.0146	-0.000228
5/2/12	87.2	5232	312.5	1.8	0.0145	-0.000228
5/2/12	88.98333333	5339	312.5	1.8	0.0145	-0.000228

Appendix B DRYING: SECOND TRIAL **SAMPLE B3 (complete)**
TREATMENT: REMMERS KSE 300 E



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
-1.34E-02	-9.94E-01	-2.73E-05	-9.56E-01	1.0	2.1

APPENDIX B: DRYING CURVE DATA, SAMPLE B3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/21/12	0	0	317.4	6.7	0.0535	-1.34E-02
5/21/12	0.033333333	2	317.3	6.6	0.0531	-1.34E-02
5/21/12	0.066666667	4	317.3	6.6	0.0528	-1.34E-02
5/21/12	0.1	6	317.2	6.5	0.0521	-1.34E-02
5/21/12	0.133333333	8	317.2	6.5	0.0518	-1.34E-02
5/21/12	0.166666667	10	317.1	6.4	0.0514	-1.34E-02
5/21/12	0.2	12	317.1	6.4	0.0511	-8.40E-03
5/21/12	0.266666667	16	317.0	6.3	0.0506	-7.20E-03
5/21/12	0.3	18	317.0	6.3	0.0503	-4.80E-03
5/21/12	0.35	21	317.0	6.3	0.0501	-4.80E-03
5/21/12	0.433333333	26	316.9	6.2	0.0497	-8.00E-03
5/21/12	0.483333333	29	316.9	6.2	0.0493	-4.80E-03
5/21/12	0.55	33	316.8	6.1	0.0490	-3.20E-03
5/21/12	0.65	39	316.8	6.1	0.0486	-3.20E-03
5/21/12	0.7	42	316.8	6.1	0.0485	-6.00E-03
5/21/12	0.766666667	46	316.7	6.0	0.0481	-3.60E-03
5/21/12	0.833333333	50	316.7	6.0	0.0478	-3.84E-03
5/21/12	1	60	316.6	5.9	0.0472	-2.88E-03
5/21/12	1.166666667	70	316.5	5.8	0.0467	-2.64E-03
5/21/12	1.5	90	316.4	5.7	0.0458	-2.88E-03
5/21/12	1.583333333	95	316.4	5.7	0.0456	-2.24E-03
5/21/12	1.833333333	110	316.3	5.6	0.0450	-1.92E-03

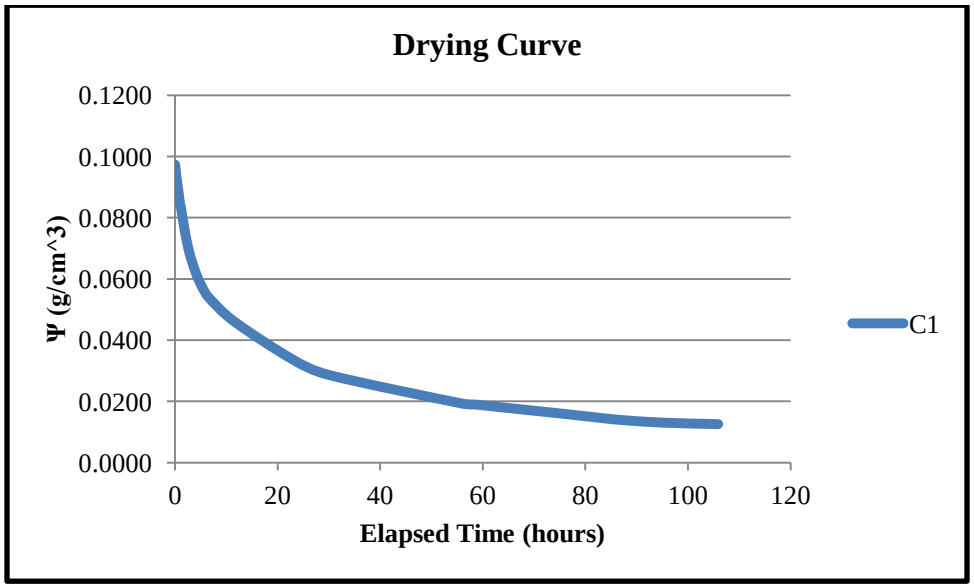
APPENDIX B: DRYING CURVE DATA, SAMPLE B3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/21/12	2	120	316.3	5.6	0.0447	-1.92E-03
5/21/12	2.25	135	316.2	5.5	0.0442	-3.05E-03
5/21/12	2.433333333	146	316.2	5.5	0.0437	-2.06E-03
5/21/12	2.666666667	160	316.1	5.4	0.0432	-1.88E-03
5/21/12	3.05	183	316.0	5.3	0.0425	-1.60E-03
5/21/12	3.45	207	315.9	5.2	0.0418	-1.60E-03
5/21/12	4.65	279	315.7	5.0	0.0399	-1.29E-03
5/21/12	5.333333333	320	315.6	4.9	0.0390	-1.20E-03
5/21/12	5.533333333	332	315.6	4.9	0.0388	-1.20E-03
5/21/12	5.933333333	356	315.5	4.8	0.0383	-9.60E-04
5/21/12	6.266666667	376	315.5	4.8	0.0380	-1.14E-03
5/21/12	6.616666667	397	315.4	4.7	0.0376	-1.07E-03
5/21/12	7.216666667	433	315.3	4.6	0.0370	-8.73E-04
5/21/12	7.766666667	466	315.3	4.6	0.0365	-1.08E-03
5/21/12	8.433333333	506	315.2	4.5	0.0358	-8.47E-04
5/21/12	9	540	315.1	4.4	0.0353	-5.51E-04
5/21/12	20.03333333	1202	314.4	3.7	0.0292	-3.41E-04
5/22/12	27.53333333	1652	314.0	3.3	0.0266	-2.06E-04
5/23/12	46.51666667	2791	313.5	2.8	0.0227	-1.31E-04
5/24/12	71.63333333	4298	313.1	2.4	0.0194	-8.69E-05
5/25/12	93.73333333	5624	312.9	2.2	0.0175	-4.13E-05
5/27/12	142.1666667	8530	312.6	1.9	0.0155	-2.93E-05

APPENDIX B: DRYING CURVE DATA, SAMPLE B3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/29/12	188.5166667	11311	312.5	1.8	0.0142	-2.73E-05
6/1/12	259.7166667	15583	312.0	1.3	0.0106	-2.73E-05
6/4/12	337.2833333	20237	312.0	1.3	0.0103	-2.73E-05
6/5/12	360.3	21618	311.9	1.2	0.0094	-2.73E-05

Appendix B DRYING **SAMPLE C1 (incomplete)**
TREATMENT: UNTREATED (CONTROL)



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
-0.0117	-0.997	-0.000146	-0.980	0.79	3.04

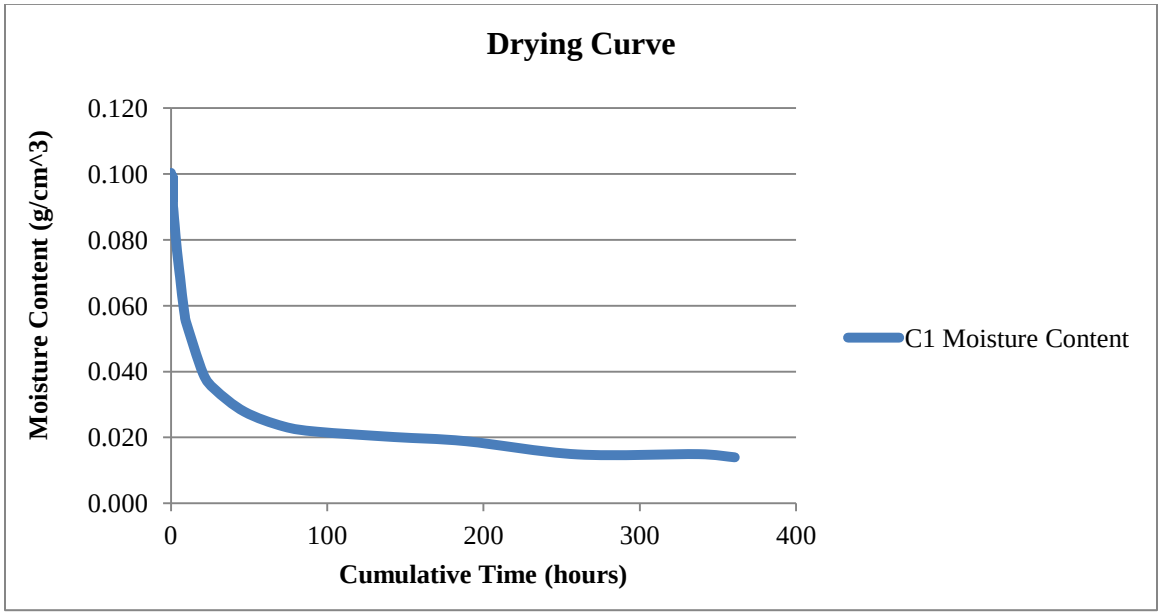
APPENDIX B: DRYING CURVE DATA, SAMPLE C1 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/26/12	0.033333333	2	327.6	12.2	0.0974	-0.0117
4/26/12	0.066666667	4	327.5	12.1	0.0967	-0.0117
4/26/12	0.1	6	327.4	12.0	0.0962	-0.0117
4/26/12	0.133333333	8	327.4	12.0	0.0958	-0.0117
4/26/12	0.166666667	10	327.3	11.9	0.0953	-0.0117
4/26/12	0.2	12	327.3	11.9	0.0948	-0.0117
4/26/12	0.233333333	14	327.2	11.8	0.0943	-0.0117
4/26/12	0.266666667	16	327.1	11.7	0.0938	-0.0117
4/26/12	0.333333333	20	327.0	11.6	0.0929	-0.0117
4/26/12	0.416666667	25	326.9	11.5	0.0917	-0.0117
4/26/12	0.5	30	326.7	11.3	0.0906	-0.0117
4/26/12	0.583333333	35	326.6	11.2	0.0897	-0.0117
4/26/12	0.666666667	40	326.5	11.1	0.0887	-0.0117
4/26/12	0.75	45	326.4	11.0	0.0876	-0.0117
4/26/12	0.833333333	50	326.2	10.8	0.0866	-0.0117
4/26/12	0.916666667	55	326.1	10.7	0.0854	-0.0117
4/26/12	1	60	326.0	10.6	0.0845	-0.0117
4/26/12	1.166666667	70	325.8	10.4	0.0833	-0.0117
4/26/12	1.333333333	80	325.6	10.2	0.0815	-0.0117
4/26/12	1.5	90	325.4	10.0	0.0798	-0.0117
4/26/12	1.666666667	100	325.2	9.8	0.0781	-0.0117
4/26/12	1.833333333	110	325.0	9.6	0.0764	-0.0117

APPENDIX B: DRYING CURVE DATA, SAMPLE C1 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/26/12	2.083333333	125	324.7	9.3	0.0742	-0.00829
4/26/12	2.45	147	324.3	8.9	0.0711	-0.00702
4/26/12	2.883333333	173	323.9	8.5	0.0681	-0.00551
4/26/12	3.333333333	200	323.6	8.2	0.0656	-0.00489
4/26/12	4.233333333	254	323.1	7.7	0.0612	-0.00357
4/26/12	5.466666667	328	322.5	7.1	0.0568	-0.00250
4/26/12	6.683333333	401	322.1	6.7	0.0538	-0.00156
4/27/12	11.7	702	321.1	5.7	0.0459	-0.00108
4/27/12	23.13333333	1388	319.6	4.2	0.0335	-0.00070
4/27/12	30.18333333	1811	319.0	3.6	0.0286	-0.00036
4/28/12	55.76666667	3346	317.8	2.4	0.0194	-0.00013
4/28/12	58.78333333	3527	317.8	2.4	0.0190	-0.000146
4/29/12	61.73333333	3704	317.7	2.3	0.0184	-0.000146
4/29/12	74.95	4497	317.4	2.0	0.0161	-0.000146
4/30/12	84.05	5043	317.2	1.8	0.0144	-0.000146
4/30/12	87.6	5256	317.1	1.7	0.0138	-0.000146
4/30/12	95.25	5715	317.0	1.6	0.0130	-0.000146
4/30/12	105.8833333	6353	317.0	1.6	0.0126	-0.000146

Appendix B DRYING: SECOND TRIAL **SAMPLE C1 (complete)**
TREATMENT: UNTREATED (CONTROL)



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
-1.34E-02	-9.94E-01	-2.73E-05	-9.56E-01	1.0	2.1

APPENDIX B: DRYING CURVE DATA, SAMPLE C1 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/21/12	0	0	327.9	12.5	0.100	3.20E-02
5/21/12	0.033333333	2	327.9	12.5	0.100	3.20E-02
5/21/12	0.066666667	4	327.8	12.4	0.0990	3.20E-02
5/21/12	0.1	6	327.7	12.3	0.0987	3.20E-02
5/21/12	0.133333333	8	327.7	12.3	0.0982	3.20E-02
5/21/12	0.166666667	10	327.6	12.2	0.0975	3.20E-02
5/21/12	0.216666667	13	327.6	12.2	0.0972	-9.60E-03
5/21/12	0.25	15	327.5	12.1	0.0969	-8.00E-03
5/21/12	0.3	18	327.5	12.1	0.0965	-4.80E-03
5/21/12	0.333333333	20	327.4	12.0	0.0963	-1.20E-02
5/21/12	0.366666667	22	327.4	12.0	0.0959	-7.20E-03
5/21/12	0.4	24	327.4	12.0	0.0957	-7.20E-03
5/21/12	0.433333333	26	327.3	11.9	0.0954	-4.80E-03
5/21/12	0.466666667	28	327.3	11.9	0.0953	-4.80E-03
5/21/12	0.5	30	327.3	11.9	0.0951	-6.86E-03
5/21/12	0.616666667	37	327.2	11.8	0.0943	-6.40E-03
5/21/12	0.666666667	40	327.2	11.8	0.0940	-5.76E-03
5/21/12	0.75	45	327.1	11.7	0.0935	-5.76E-03
5/21/12	0.833333333	50	327.0	11.6	0.0930	-6.72E-03
5/21/12	0.916666667	55	327.0	11.6	0.0925	-4.80E-03
5/21/12	1	60	326.9	11.5	0.0921	4.32E-02
5/21/12	1.166666667	70	327.8	12.4	0.0993	-5.38E-02

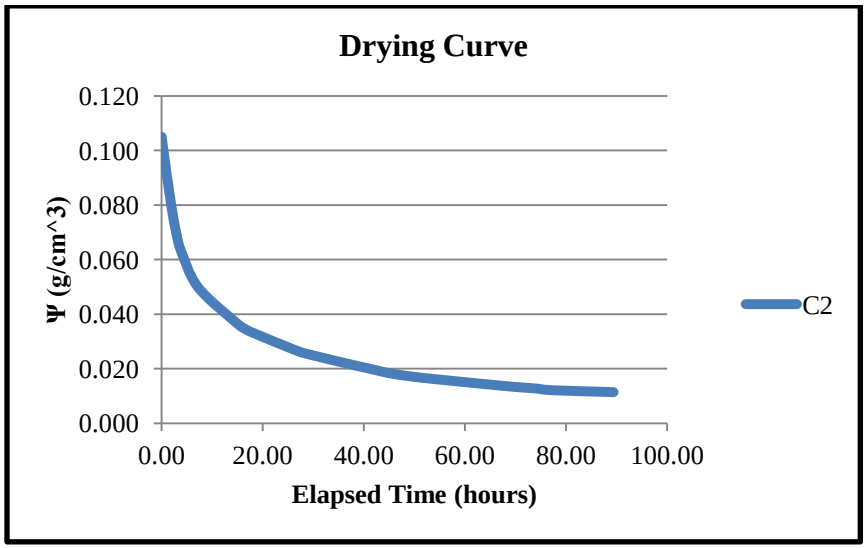
APPENDIX B: DRYING CURVE DATA, SAMPLE C1 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/21/12	1.333333333	80	326.7	11.3	0.0903	-4.80E-03
5/21/12	1.5	90	326.6	11.2	0.0895	-5.76E-03
5/21/12	1.666666667	100	326.5	11.1	0.0886	-5.76E-03
5/21/12	1.833333333	110	326.4	11.0	0.0876	-6.24E-03
5/21/12	2	120	326.2	10.8	0.0866	-5.04E-03
5/21/12	2.333333333	140	326.0	10.6	0.0849	-5.36E-03
5/21/12	2.616666667	157	325.8	10.4	0.0834	-6.00E-03
5/21/12	2.95	177	325.6	10.2	0.0814	-4.80E-03
5/21/12	3.283333333	197	325.4	10.0	0.0798	-5.09E-03
5/21/12	3.833333333	230	325.0	9.6	0.0770	-4.27E-03
5/21/12	3.983333333	239	324.9	9.5	0.0763	-4.20E-03
5/21/12	5.183333333	311	324.3	8.9	0.0713	-3.84E-03
5/21/12	5.85	351	324.0	8.6	0.0687	-4.40E-03
5/21/12	6.05	363	323.9	8.5	0.0678	-4.42E-03
5/21/12	6.466666667	388	323.7	8.3	0.0660	-4.29E-03
5/21/12	6.783333333	407	323.5	8.1	0.0646	-4.32E-03
5/21/12	7.116666667	427	323.3	7.9	0.0632	-3.60E-03
5/21/12	7.716666667	463	323.0	7.6	0.0610	-3.67E-03
5/21/12	8.283333333	497	322.8	7.4	0.0590	-3.20E-03
5/21/12	8.983333333	539	322.5	7.1	0.0567	-2.70E-03
5/21/12	9.516666667	571	322.3	6.9	0.0553	-1.43E-03
5/21/12	20.56666667	1234	320.3	4.9	0.0394	-6.40E-04

APPENDIX B: DRYING CURVE DATA, SAMPLE C1 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/22/12	47.03333333	2822	318.9	3.5	0.0278	-1.78E-04
5/24/12	72.15	4329	318.3	2.9	0.0234	0.00E+00
5/25/12	93.81666667	5629	318.1	2.7	0.0218	0.00E+00
5/27/12	142.6833333	8561	317.9	2.5	0.0202	0.00E+00
5/29/12	189.0166667	11341	317.8	2.4	0.0189	0.00E+00
6/1/12	260.2333333	15614	317.3	1.9	0.0149	0.00E+00
6/4/12	337.8166667	20269	317.3	1.9	0.0150	0.00E+00
6/5/12	360.8166667	21649	317.2	1.8	0.0140	0.00E+00

Appendix B DRYING **SAMPLE C2 (incomplete)**
TREATMENT: UNTREATED (CONTROL)



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
-0.01320	-0.999	-0.000246	-0.963	0.47	2.1

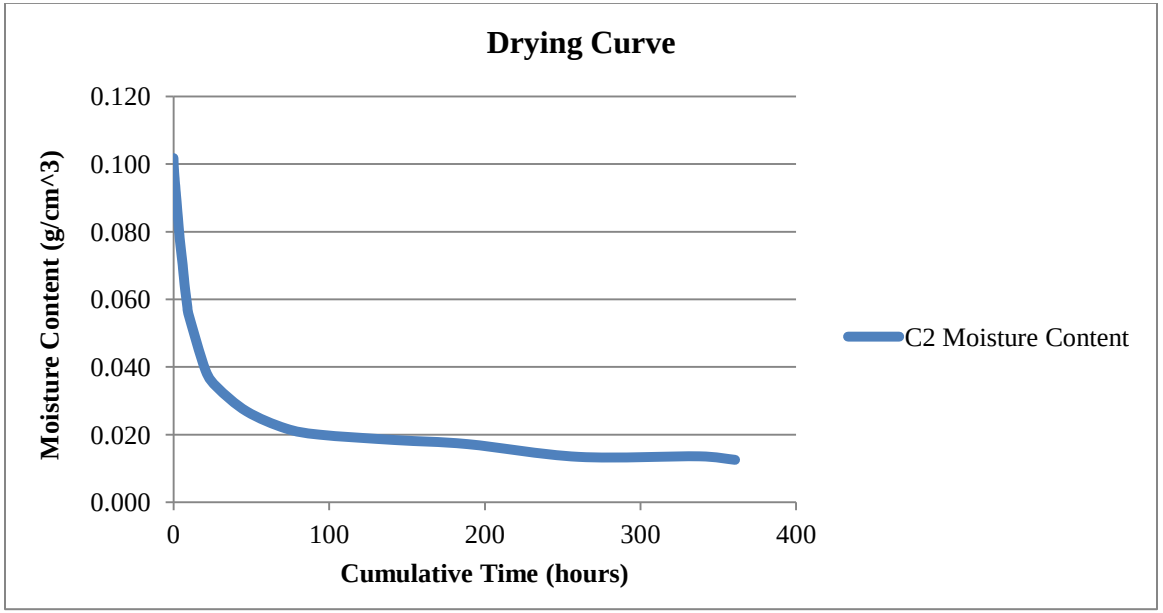
APPENDIX B: DRYING CURVE DATA, SAMPLE C2 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/22/12	0.03	2	306.5	13.1	0.105	-0.00897
4/22/12	0.07	4	306.5	13.1	0.104	-0.00897
4/22/12	0.10	6	306.4	13.0	0.104	-0.00897
4/22/12	0.13	8	306.3	12.9	0.104	--0.00897
4/22/12	0.17	10	306.3	12.9	0.103	-0.00897
4/22/12	0.20	12	306.2	12.8	0.103	-0.00897
4/22/12	0.23	14	306.2	12.8	0.102	-0.00897
4/22/12	0.27	16	306.1	12.7	0.102	-0.00897
4/22/12	0.33	20	306.0	12.6	0.101	-0.00897
4/22/12	0.42	25	305.8	12.4	0.0994	-0.00897
4/22/12	0.50	30	305.7	12.3	0.0982	-0.00897
4/22/12	0.58	35	305.6	12.2	0.0972	-0.00897
4/22/12	0.67	40	305.4	12.0	0.0960	-0.00897
4/22/12	0.75	45	305.3	11.9	0.0948	-0.00897
4/22/12	0.83	50	305.1	11.7	0.0937	-0.00897
4/22/12	0.92	55	305.0	11.6	0.0926	-0.00897
4/22/12	1.00	60	304.8	11.4	0.0914	-0.00897
4/22/12	1.17	70	304.6	11.2	0.0894	-0.00897
4/22/12	1.33	80	304.3	10.9	0.0874	-0.00897
4/22/12	1.50	90	304.0	10.6	0.0850	-0.00897
4/22/12	1.67	100	303.8	10.4	0.0830	-0.00897
4/22/12	2.00	120	303.3	9.9	0.0790	-0.00897

APPENDIX B: DRYING CURVE DATA, SAMPLE C2 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/22/12	2.17	130	303.0	9.6	0.0770	-0.0104
4/22/12	2.55	153	302.5	9.1	0.0730	-0.0093
4/22/12	2.83	170	302.2	8.8	0.0704	-0.0089
4/22/12	3.17	190	301.8	8.4	0.0674	-0.0064
4/22/12	3.75	225	301.4	8.0	0.0637	-0.0040
4/22/12	7.25	435	299.6	6.2	0.0498	-0.0017
4/23/12	15.42	925	297.9	4.5	0.0358	-0.0012
4/23/12	16.58	995	297.7	4.3	0.0345	-0.0010
4/23/12	17.58	1055	297.6	4.2	0.0335	-0.0008
4/23/12	25.55	1533	296.8	3.4	0.0274	-0.000246
4/23/12	28.65	1719	296.6	3.2	0.0254	-0.000246
4/24/12	39.67	2380	296.0	2.6	0.0206	-0.000246
4/24/12	40.53	2432	295.9	2.5	0.0202	-0.000246
4/24/12	41.80	2508	295.9	2.5	0.0197	-0.000246
4/24/12	46.00	2760	295.7	2.3	0.0180	-0.000246
4/24/12	53.12	3187	295.4	2.0	0.0163	-0.000246
4/25/12	69.35	4161	295.1	1.7	0.0134	-0.000246
4/25/12	72.92	4375	295.0	1.6	0.0129	-0.000246
4/25/12	74.68	4481	295.0	1.6	0.0126	-0.000246
4/25/12	76.95	4617	294.9	1.5	0.0121	-0.000246
4/26/12	89.38	5363	294.8	1.4	0.0114	-0.000246

Appendix B DRYING: SECOND TRIAL **SAMPLE C2 (complete)**
TREATMENT: UNTREATED (CONTROL)



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
-5.84E-03	-9.95E-01	-3.04E-05	-9.68E-01	0.8	3.6

APPENDIX B: DRYING CURVE DATA, SAMPLE C2 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/21/12	0	0	306.1	12.7	0.102	-5.84E-03
5/21/12	0.033333333	2	306.1	12.7	0.101	-5.84E-03
5/21/12	0.066666667	4	306.0	12.6	0.101	-5.84E-03
5/21/12	0.1	6	305.9	12.5	0.100	-5.84E-03
5/21/12	0.133333333	8	305.9	12.5	0.0998	-5.84E-03
5/21/12	0.166666667	10	305.8	12.4	0.0994	-5.84E-03
5/21/12	0.216666667	13	305.8	12.4	0.0990	-5.84E-03
5/21/12	0.25	15	305.8	12.4	0.0988	-5.84E-03
5/21/12	0.3	18	305.7	12.3	0.0985	-5.84E-03
5/21/12	0.333333333	20	305.7	12.3	0.0982	-5.84E-03
5/21/12	0.366666667	22	305.7	12.3	0.0980	-5.84E-03
5/21/12	0.4	24	305.6	12.2	0.0977	-5.84E-03
5/21/12	0.433333333	26	305.6	12.2	0.0974	-5.84E-03
5/21/12	0.466666667	28	305.6	12.2	0.0973	-5.84E-03
5/21/12	0.5	30	305.5	12.1	0.0970	-5.84E-03
5/21/12	0.616666667	37	305.4	12.0	0.0963	-5.84E-03
5/21/12	0.666666667	40	305.4	12.0	0.0961	-5.84E-03
5/21/12	0.75	45	305.4	12.0	0.0956	-5.84E-03
5/21/12	0.833333333	50	305.3	11.9	0.0950	-5.84E-03
5/21/12	0.916666667	55	305.2	11.8	0.0946	-5.84E-03
5/21/12	1	60	305.2	11.8	0.0941	-5.84E-03
5/21/12	1.166666667	70	305.1	11.7	0.0934	-5.84E-03

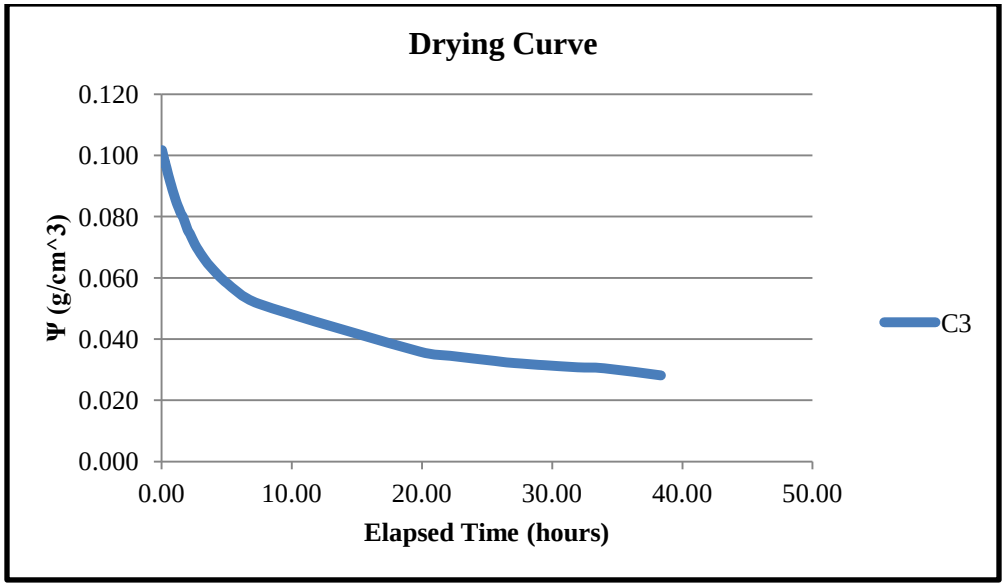
APPENDIX B: DRYING CURVE DATA, SAMPLE C2 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/21/12	1.333333333	80	304.9	11.5	0.0923	-5.84E-03
5/21/12	1.5	90	304.8	11.4	0.0915	-5.84E-03
5/21/12	1.666666667	100	304.7	11.3	0.0906	-5.84E-03
5/21/12	1.833333333	110	304.6	11.2	0.0898	-5.84E-03
5/21/12	2	120	304.5	11.1	0.0889	-5.84E-03
5/21/12	2.333333333	140	304.3	10.9	0.0870	-5.84E-03
5/21/12	2.616666667	157	304.1	10.7	0.0854	-5.84E-03
5/21/12	2.95	177	303.9	10.5	0.0837	-5.84E-03
5/21/12	3.283333333	197	303.6	10.2	0.0817	-5.09E-03
5/21/12	3.833333333	230	303.3	9.9	0.0789	-5.33E-03
5/21/12	3.983333333	239	303.2	9.8	0.0781	-4.20E-03
5/21/12	5.183333333	311	302.5	9.1	0.0730	-3.84E-03
5/21/12	5.85	351	302.2	8.8	0.0705	-5.20E-03
5/21/12	6.05	363	302.1	8.7	0.0694	-4.80E-03
5/21/12	6.466666667	388	301.8	8.4	0.0674	-4.55E-03
5/21/12	6.783333333	407	301.7	8.3	0.0660	-4.80E-03
5/21/12	7.116666667	427	301.5	8.1	0.0644	-3.87E-03
5/21/12	7.716666667	463	301.2	7.8	0.0621	-3.53E-03
5/21/12	8.283333333	497	300.9	7.5	0.0601	-3.66E-03
5/21/12	8.983333333	539	300.6	7.2	0.0575	-3.15E-03
5/21/12	9.516666667	571	300.4	7.0	0.0558	-1.52E-03
5/21/12	20.56666667	1234	298.3	4.9	0.0390	-6.72E-04

APPENDIX B: DRYING CURVE DATA, SAMPLE C2 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
5/22/12	28.06666667	1684	297.7	4.3	0.0340	-3.75E-04
5/23/13	47.03333333	2822	296.8	3.4	0.0269	-2.01E-04
5/24/12	72.15	4329	296.1	2.7	0.0218	-3.04E-05
5/25/12	93.81666667	5629	295.9	2.5	0.0200	-3.04E-05
5/27/12	142.6833333	8561	295.7	2.3	0.0184	-3.04E-05
5/29/12	189.0166667	11341	295.6	2.2	0.0172	-3.04E-05
6/1/12	260.2333333	15614	295.1	1.7	0.0134	-3.04E-05
6/4/12	337.8166667	20269	295.1	1.7	0.0136	-3.04E-05
6/5/12	360.8166667	21649	295.0	1.6	0.0126	-3.04E-05

Appendix B DRYING **SAMPLE C3 (incomplete)**
TREATMENT: UNTREATED (CONTROL)



INITIAL DRYING RATE	INITIAL DRYING RATE CORRELATION FACTOR	FINAL DRYING RATE	FINAL DRYING RATE CORRELATION FACTOR	CRITICAL RELATIVE MOISTURE CONTENT	CRITICAL RESIDUAL WATER CONTENT
-0.0145	-0.996	-0.00039	-0.987	0.794	3.26

APPENDIX B: DRYING CURVE DATA, SAMPLE C3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/25/12	0.03	2	322.1	12.7	0.102	-0.0145
4/25/12	0.07	4	322.0	12.6	0.101	-0.0145
4/25/12	0.10	6	322.0	12.6	0.101	-0.0145
4/25/12	0.13	8	321.9	12.5	0.100	-0.0145
4/25/12	0.17	10	321.8	12.4	0.0994	-0.0145
4/25/12	0.20	12	321.6	12.2	0.0974	-0.0145
4/25/12	0.23	14	321.7	12.3	0.0982	-0.0145
4/25/12	0.27	16	321.6	12.2	0.0977	-0.0145
4/25/12	0.33	20	321.5	12.1	0.0966	-0.0145
4/25/12	0.42	25	321.3	11.9	0.0953	-0.0145
4/25/12	0.50	30	321.1	11.7	0.0938	-0.0145
4/25/12	0.58	35	321.0	11.6	0.0926	-0.0145
4/25/12	0.67	40	320.8	11.4	0.0913	-0.0145
4/25/12	0.75	45	320.7	11.3	0.0901	-0.0145
4/25/12	0.83	50	320.5	11.1	0.0888	-0.0145
4/25/12	0.92	55	320.4	11.0	0.0877	-0.0145
4/25/12	1.00	60	320.2	10.8	0.0866	-0.0145
4/25/12	1.17	70	320.0	10.6	0.0844	-0.0145
4/25/12	1.33	80	319.7	10.3	0.0826	-0.0145
4/25/12	1.50	90	319.5	10.1	0.0809	-0.0145
4/25/12	1.67	100	319.4	10.0	0.0797	-0.0120
4/25/12	2.00	120	318.9	9.5	0.0757	-0.0072
4/25/12	2.17	130	318.7	9.3	0.0745	-0.0090

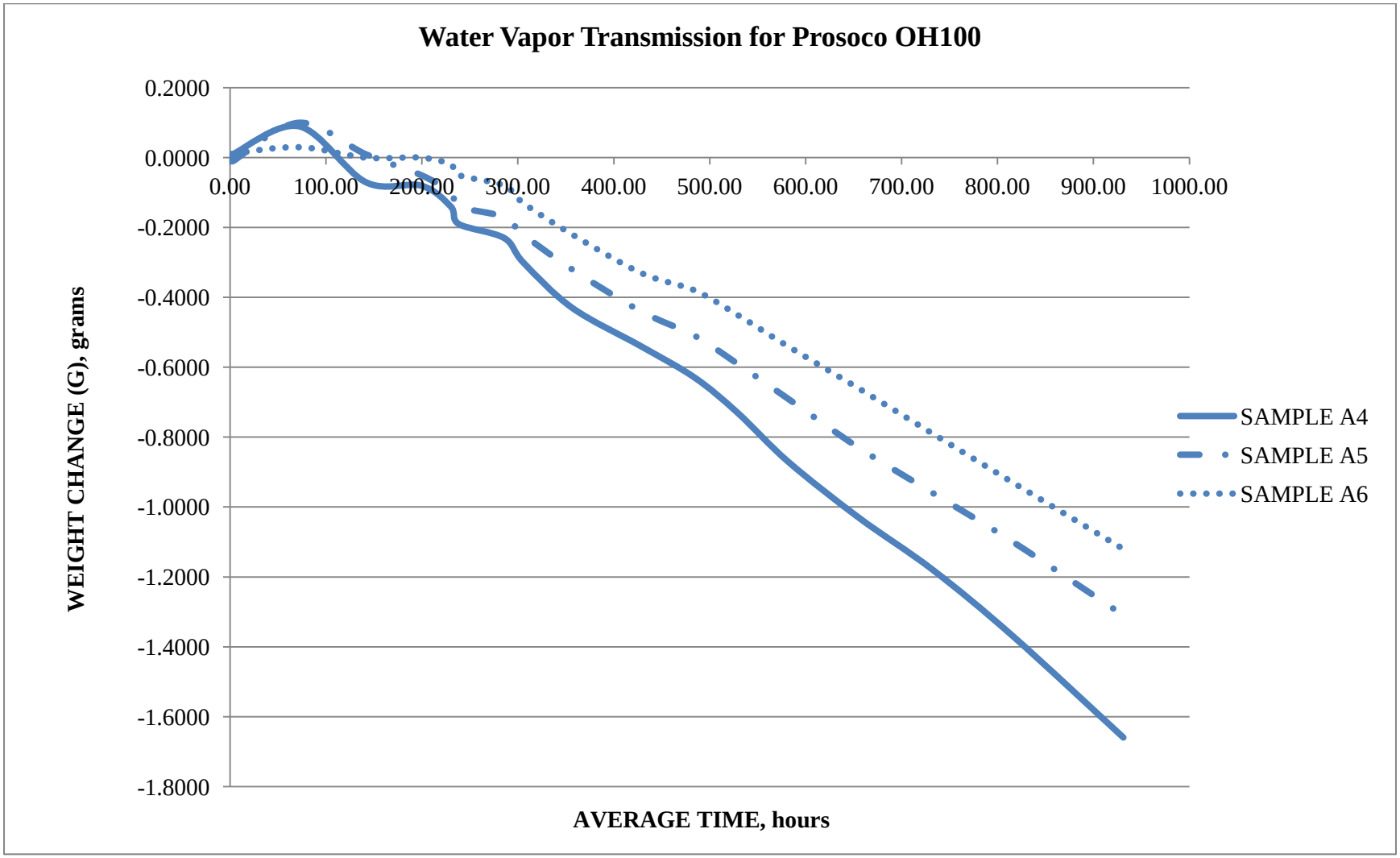
APPENDIX B: DRYING CURVE DATA, SAMPLE C3 (CONTINUED)

DATE	TIME ELAPSED (hours)	TIME ELAPSED (min)	MASS (g)	Ut (g)	Ψ (g/cm^3)	DRYING RATE (g/cm^3)
4/25/12	2.55	153	318.3	8.9	0.0710	-0.00706
4/25/12	2.83	170	318.0	8.6	0.0690	-0.00648
4/25/12	3.17	190	317.8	8.4	0.0669	-0.00549
4/25/12	3.75	225	317.4	8.0	0.0637	-0.00421
4/25/12	5.08	305	316.7	7.3	0.0581	-0.00275
4/25/12	7.43	446	315.9	6.5	0.0516	-0.00127
4/26/12	19.83	1190	313.9	4.5	0.0359	-0.000389
4/26/12	22.17	1330	313.7	4.3	0.0346	-0.000389
4/26/12	25.60	1536	313.5	4.1	0.0329	-0.000389
4/26/12	26.50	1590	313.5	4.1	0.0324	-0.000389
4/26/12	27.73	1664	313.4	4.0	0.0320	-0.000389
4/26/12	28.95	1737	313.4	4.0	0.0316	-0.000389
4/26/12	29.32	1759	313.3	3.9	0.0315	-0.000389
4/26/12	31.97	1918	313.3	3.9	0.0308	-0.000389
4/27/12	34.00	2040	313.2	3.8	0.0305	-0.000389
4/27/12	38.35	2301	312.9	3.5	0.0282	-0.000389

Appendix C WATER VAPOR TRANSMISSION

PROSOCO OH100			SAMPLE A4			SAMPLE A5			SAMPLE A6	
DATE	CUMULATIVE TIME (hours)		MASS (g)	WEIGHT CHANGE (g)		MASS (g)	WEIGHT CHANGE (g)		MASS (g)	WEIGHT CHANGE (g)
4/13/12	683.53		565.03	0.0000		455.35	0.0000		463.47	0.0000
4/13/12	683.53		565.04	0.0100		455.35	0.0000		463.47	0.0000
4/13/12	683.53		565.04	0.0100		455.34	-0.0100		463.46	-0.0100
4/13/12	683.53		565.04	0.0100		455.34	-0.0100		463.48	0.0100
4/14/12	683.55		565.12	0.0900		455.45	0.1000		463.50	0.0300
4/15/12	683.57		564.96	-0.0700		455.36	0.0100		463.47	0.0000
4/16/12	683.58		564.95	-0.0800		455.30	-0.0500		463.47	0.0000
4/16/12	683.58		564.89	-0.1400		455.25	-0.1000		463.45	-0.0200
4/16/12	683.58		564.84	-0.1900		455.21	-0.1400		463.42	-0.0500
4/17/12	683.60		564.80	-0.2300		455.18	-0.1700		463.39	-0.0800
4/17/12	683.60		564.73	-0.3000		455.13	-0.2200		463.34	-0.1300
4/18/12	683.62		564.60	-0.4300		455.03	-0.3200		463.25	-0.2200
4/19/12	683.63		564.49	-0.5400		454.91	-0.4400		463.14	-0.3300
4/20/12	683.65		564.40	-0.6300		454.84	-0.5100		463.09	-0.3800
4/20/12	683.65		564.30	-0.7300		454.76	-0.5900		463.02	-0.4500
4/21/12	683.67		564.16	-0.8700		454.66	-0.6900		462.93	-0.5400
4/22/12	683.68		564.00	-1.0300		454.52	-0.8300		462.81	-0.6600
4/23/12	683.70		563.85	-1.1800		454.39	-0.9600		462.68	-0.7900
4/24/12	683.72		563.66	-1.3700		454.25	-1.1000		462.54	-0.9300
4/26/12	683.75		563.37	-1.6600		454.04	-1.3100		462.35	-1.1200

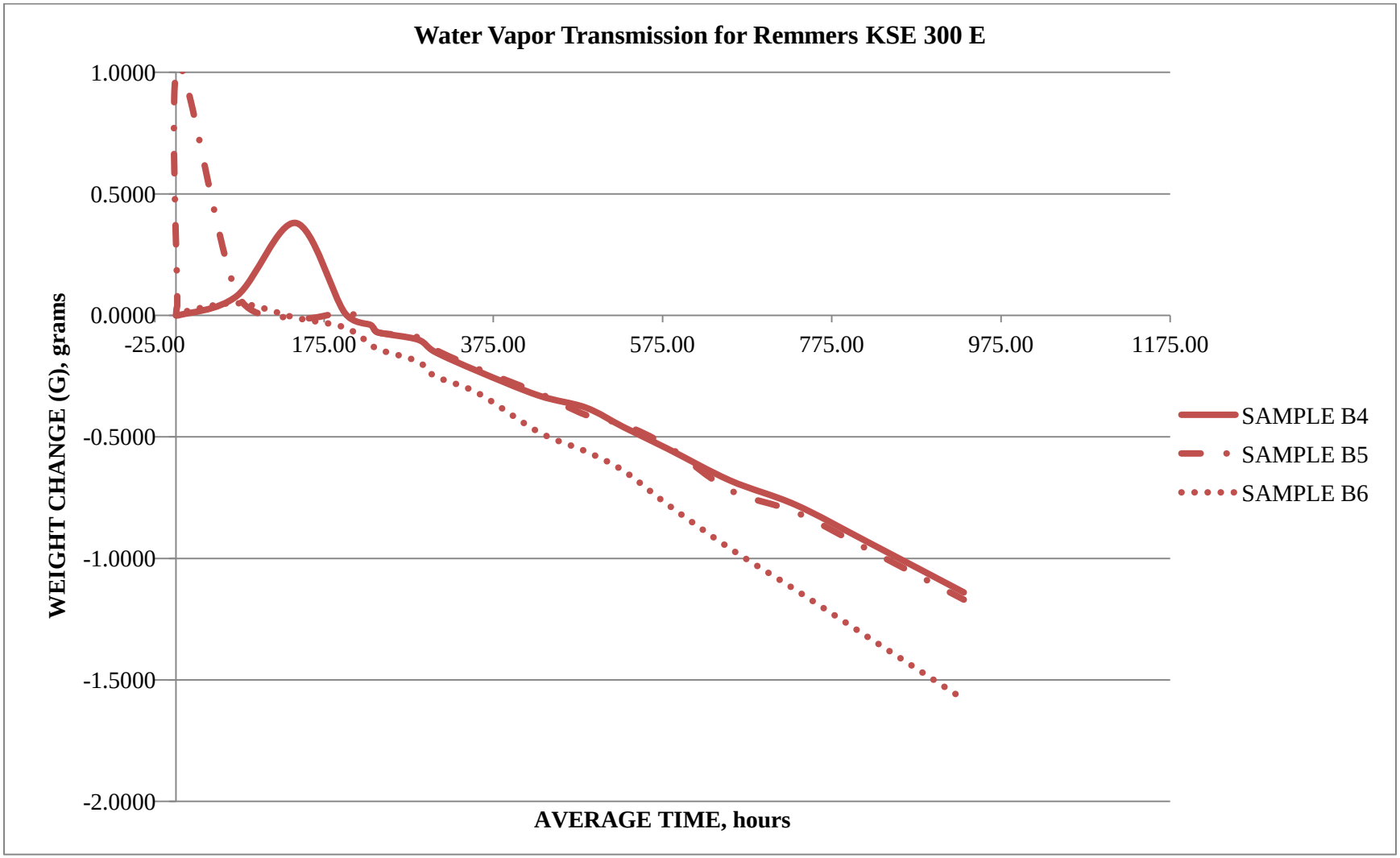
Appendix C WATER VAPOR TRANSMISSION



Appendix C WATER VAPOR TRANSMISSION

REMMERS KSE 300 E			SAMPLE B4			SAMPLE B5			SAMPLE B6	
DATE	CUMULATIVE TIME (hours)		MASS (g)	WEIGHT CHANGE (g)		MASS (g)	WEIGHT CHANGE (g)		MASS (g)	WEIGHT CHANGE (g)
4/13/12	683.53		508.42	0.0000		462.96	0.000		436.63	0.0000
4/13/12	683.53		508.42	0.0000		462.99	0.030		436.63	0.0000
4/13/12	683.53		508.42	0.0000		463.00	0.040		436.64	0.0100
4/13/12	683.53		508.42	0.0000		463.99	1.030		436.64	0.0100
4/14/12	683.55		508.50	0.0800		463.05	0.090		436.68	0.0500
4/15/12	683.57		508.80	0.3800		462.95	-0.010		436.62	-0.0100
4/16/12	683.58		508.43	0.0100		462.97	0.010		436.58	-0.0500
4/16/12	683.58		508.38	-0.0400		462.93	-0.030		436.51	-0.1200
4/16/12	683.58		508.35	-0.0700		462.89	-0.070		436.49	-0.1400
4/17/12	683.60		508.32	-0.1000		462.87	-0.090		436.44	-0.1900
4/17/12	683.60		508.27	-0.1500		462.82	-0.140		436.38	-0.2500
4/18/12	683.62		508.19	-0.2300		462.74	-0.220		436.31	-0.3200
4/19/12	683.63		508.09	-0.3300		462.64	-0.320		436.15	-0.4800
4/20/12	683.65		508.04	-0.3800		462.55	-0.410		436.07	-0.5600
4/20/12	683.65		507.96	-0.4600		462.51	-0.450		435.99	-0.6400
4/21/12	683.67		507.87	-0.5500		462.42	-0.540		435.85	-0.7800
4/22/12	683.68		507.74	-0.6800		462.24	-0.720		435.67	-0.9600
4/23/12	683.70		507.64	-0.7800		462.15	-0.810		435.50	-1.1300
4/24/12	683.72		507.49	-0.9300		462.00	-0.960		435.31	-1.3200
4/26/12	683.75		507.28	-1.1400		461.79	-1.170		435.05	-1.5800

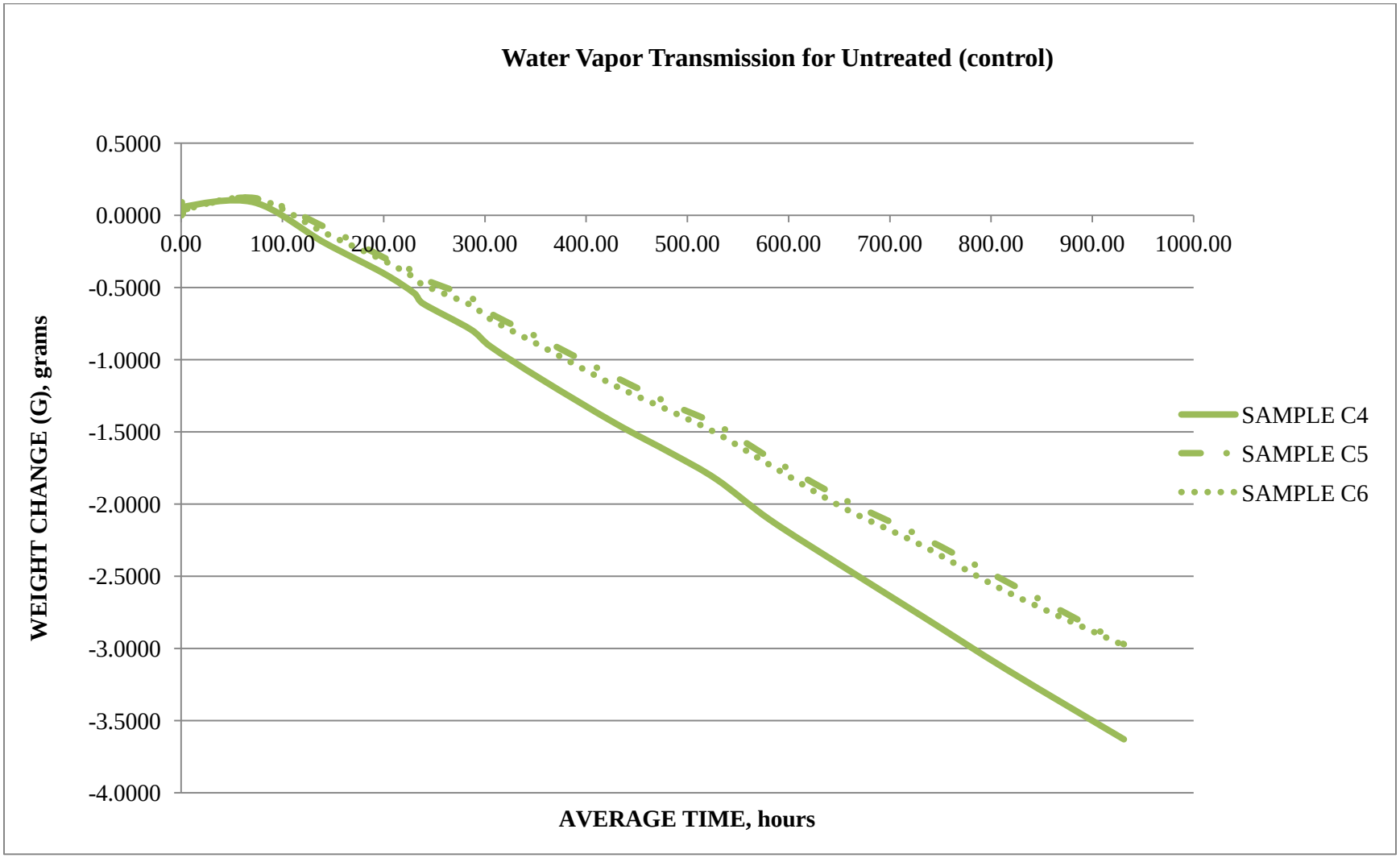
Appendix C WATER VAPOR TRANSMISSION



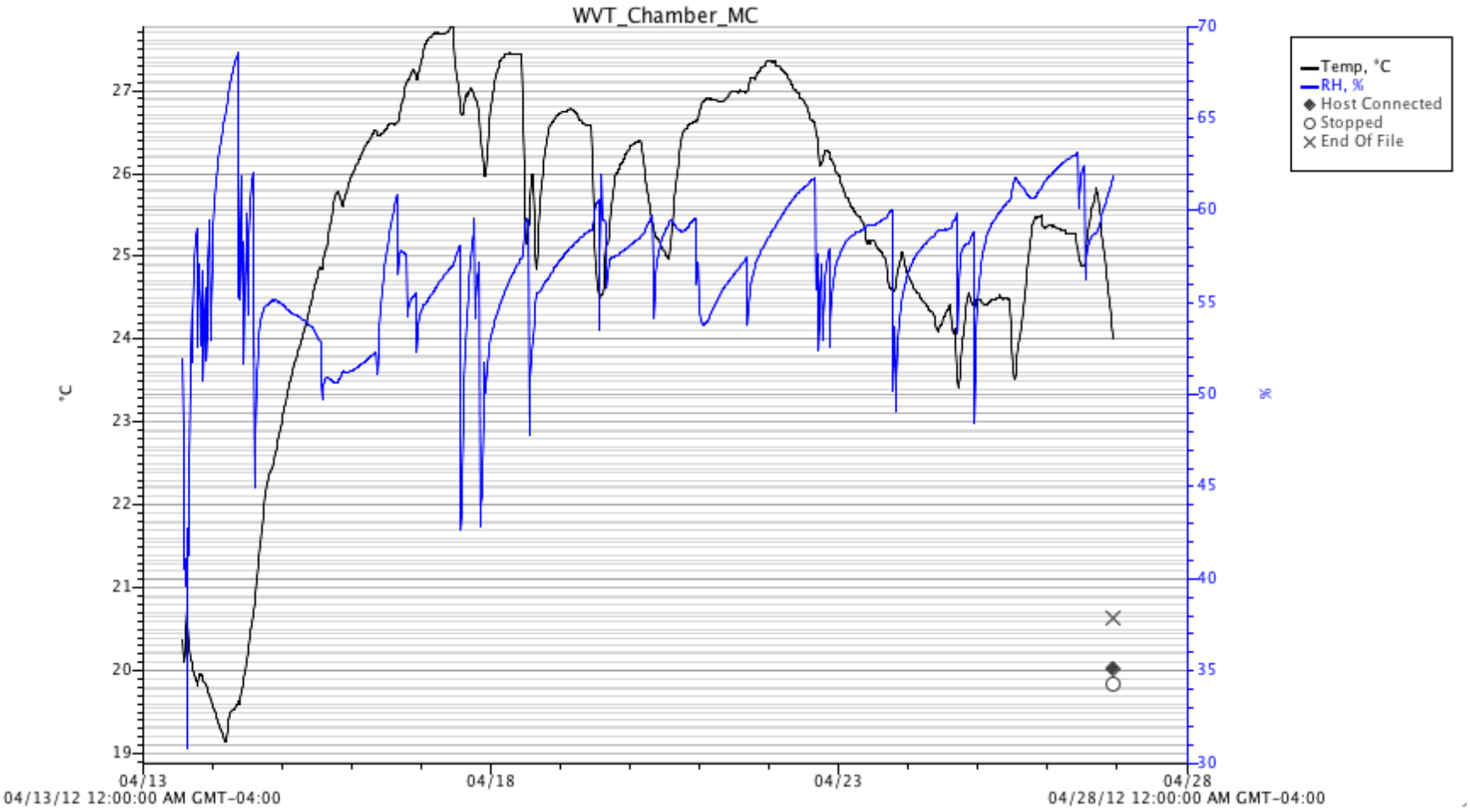
Appendix C WATER VAPOR TRANSMISSION

UNTREATED (CONTROL)			SAMPLE C4			SAMPLE C5			SAMPLE C6	
DATE	CUMULATIVE TIME (hours)		MASS (g)	WEIGHT CHANGE (g)		MASS (g)	WEIGHT CHANGE (g)		MASS (g)	WEIGHT CHANGE (g)
4/13/12	683.53		454.36	0.0000		500.69	0.0000		466.76	0.0000
4/13/12	683.53		454.38	0.0200		500.76	0.0700		466.86	0.1000
4/13/12	683.53		454.37	0.0100		500.73	0.0400		466.78	0.0200
4/13/12	683.53		454.42	0.0600		500.73	0.0400		466.80	0.0400
4/14/12	683.55		454.45	0.0900		500.81	0.1200		466.88	0.1200
4/15/12	683.57		454.17	-0.1900		500.61	-0.0800		466.64	-0.1200
4/16/12	683.58		453.96	-0.4000		500.40	-0.2900		466.45	-0.3100
4/16/12	683.58		453.82	-0.5400		500.30	-0.3900		466.33	-0.4300
4/16/12	683.58		453.75	-0.6100		500.25	-0.4400		466.28	-0.4800
4/17/12	683.60		453.57	-0.7900		500.12	-0.5700		466.14	-0.6200
4/17/12	683.60		453.45	-0.9100		500.01	-0.6800		466.04	-0.7200
4/18/12	683.62		453.22	-1.1400		499.83	-0.8600		465.85	-0.9100
4/19/12	683.63		452.92	-1.4400		499.57	-1.1200		465.58	-1.1800
4/20/12	683.65		452.71	-1.6500		499.38	-1.3100		465.40	-1.3600
4/20/12	683.65		452.53	-1.8300		499.24	-1.4500		465.25	-1.5100
4/21/12	683.67		452.25	-2.1100		499.01	-1.6800		465.03	-1.7300
4/22/12	683.68		451.92	-2.4400		498.72	-1.9700		464.73	-2.0300
4/23/12	683.70		451.58	-2.7800		498.46	-2.2300		464.47	-2.2900
4/24/12	683.72		451.21	-3.1500		498.15	-2.5400		464.15	-2.6100
4/26/12	683.75		450.73	-3.6300		497.72	-2.9700		463.78	-2.9800

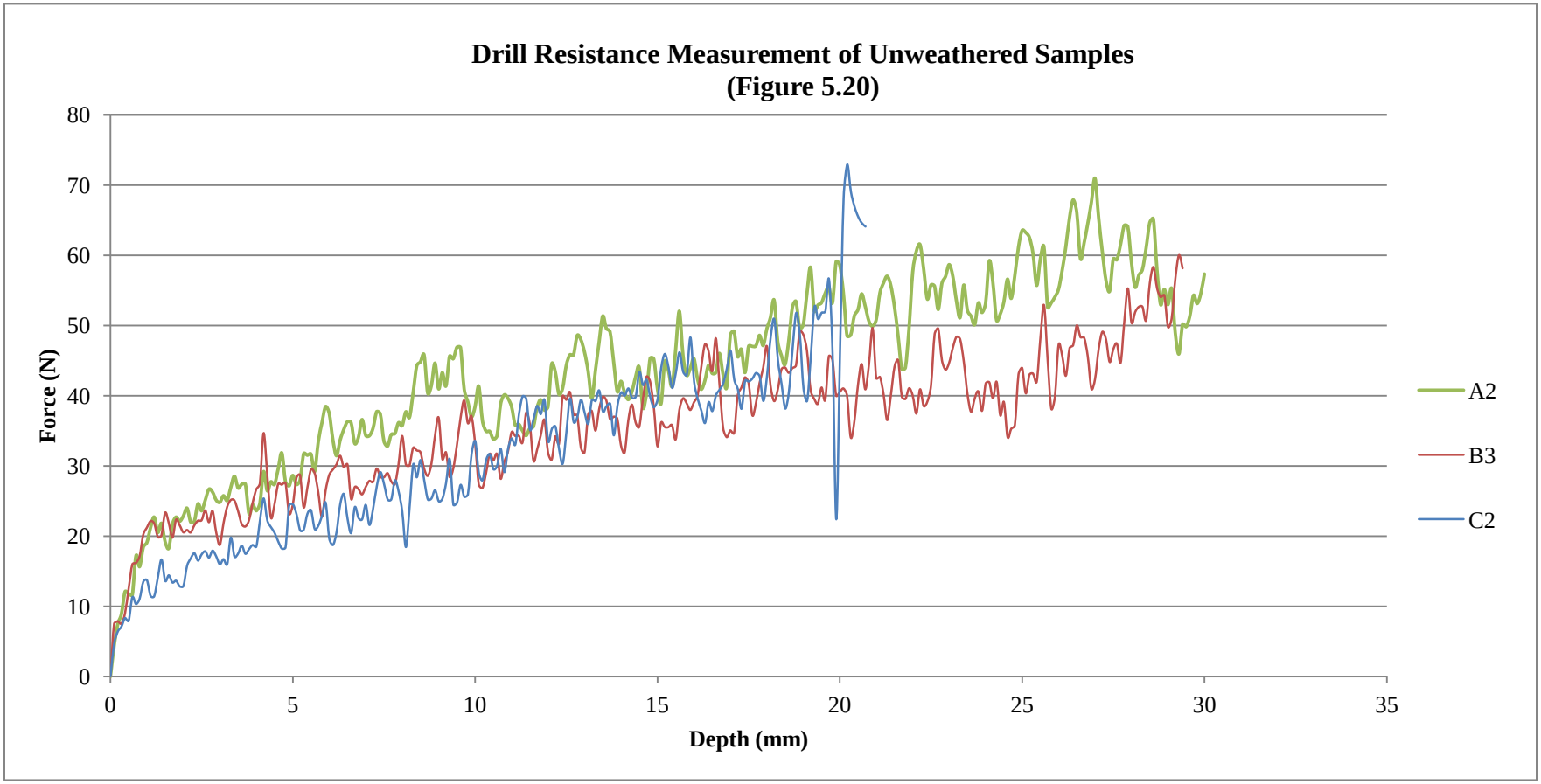
Appendix C WATER VAPOR TRANSMISSION



Appendix C WATER VAPOR TRANSMISSION: CONDITIONS AS RECORDED BY DATALOGGER



Appendix D DRILL RESISTANCE
1/8” carbide tipped bit
900 rpm
10 mm/min



Appendix D DRILL RESISTANCE: MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.20)

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
0	0	0	0
0.1	4.3	7.48	4.63
0.2	7.44	7.87	6.39
0.3	8.89	7.55	7.1
0.4	12.09	9.02	8.34
0.5	11.79	12.57	7.94
0.6	11.63	15.97	11.29
0.7	17.21	16.18	10.33
0.8	15.65	17.15	11.08
0.9	18.41	20.21	13.5
1	19.1	21.22	13.74
1.1	21.21	22.15	11.49
1.2	22.72	21.81	11.44
1.3	20.52	19.86	14.11
1.4	21.83	20.13	16.68
1.5	19.19	23.34	13.63
1.6	18.28	21.86	14.42
1.7	21.71	19.78	13.39
1.8	22.72	22.34	13.65
1.9	22.12	21.53	12.84
2	22.88	20.54	12.88
2.1	23.99	20.88	15.75
2.2	22	20.52	16.82

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
2.3	22.11	21.53	17.57
2.4	24.6	22.2	16.52
2.5	23.61	22.26	17.4
2.6	25.12	23.66	17.84
2.7	26.68	21.98	16.95
2.8	26.27	23.59	17.94
2.9	25.13	20.53	17.11
3	24.81	18.75	15.98
3.1	25.76	21.82	16.73
3.2	25.07	24.16	15.98
3.3	26.94	25.14	19.79
3.4	28.54	25.07	17.09
3.5	26.85	23.55	17.52
3.6	27.38	21.7	18.65
3.7	27.4	21.37	17.48
3.8	23.17	22.28	18.15
3.9	24.47	24.76	18.75
4	23.61	26.68	18.51
4.1	24.71	27.53	22.24
4.2	29.19	34.68	25.37
4.3	26.46	28.76	22.25
4.4	27.74	22.66	21.28
4.5	27.37	24.56	20.48

Appendix D DRILL RESISTANCE: MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.20)

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
4.6	29.56	19.24	27.42
4.7	31.85	18.22	27.31
4.8	27.74	18.38	27.57
4.9	27.15	24.39	23.18
5	28.65	24.55	24.46
5.1	27.33	23.14	28.29
5.2	27.96	20.83	28.68
5.3	31.75	20.94	24.08
5.4	31.51	23.17	26.88
5.5	31.68	23.69	29.5
5.6	29.18	21.02	28.97
5.7	33.46	21.49	26.22
5.8	36.15	22.89	22.74
5.9	38.46	24.76	26.47
6	37.48	19.63	28.71
6.1	33.73	18.73	29.48
6.2	31.44	20.6	30.21
6.3	33.7	24.55	31.44
6.4	35.2	25.99	29.79
6.5	36.31	22.51	30.21
6.6	36.15	20.45	25.29
6.7	33.19	24.13	26.98
6.8	34.04	22.59	26.7

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
6.9	36.61	25.94	22.39
7	34.35	26.99	24.45
7.1	34.29	27.86	21.59
7.2	35.35	27.72	23.87
7.3	37.72	29.61	27.05
7.4	37.4	28.46	29.11
7.5	33.52	28.37	27.43
7.6	32.81	28.96	25.21
7.7	34.48	27.78	25.24
7.8	34.6	27.41	27.93
7.9	36.16	30.23	26.35
8	35.73	34.27	23.5
8.1	37.71	30.21	18.44
8.2	36.92	30.08	24.05
8.3	40.41	32.57	30.19
8.4	44.26	32.19	28.37
8.5	44.79	31.95	30.83
8.6	45.82	29.63	28
8.7	40.38	28.58	25.23
8.8	41.43	30.25	25.35
8.9	44.64	34.3	26.54
9	40.96	36.87	24.96
9.1	43.28	30.98	25.31

Appendix D DRILL RESISTANCE: MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.20)

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
9.2	41.37	31.94	27.52
9.3	45.62	28.42	30.97
9.4	45.24	29.63	24.48
9.5	46.89	32.95	24.72
9.6	46.85	36.81	27.3
9.7	40.92	39.33	25.59
9.8	39.14	36.09	25.95
9.9	36.99	37.09	31.66
10	38.47	33.2	33.53
10.1	41.37	27.35	28.95
10.2	36.45	26.84	27.94
10.3	34.94	28.99	30.83
10.4	34.93	31.7	31.67
10.5	33.8	30.77	29.52
10.6	34.29	31.68	29.99
10.7	38.84	28.16	32.43
10.8	40.12	30.54	29.1
10.9	39.63	32.03	32.43
11	38.41	34.81	33.91
11.1	35.8	34.26	33.04
11.2	35.94	34.29	37.34
11.3	35	33.33	39.92
11.4	34.32	37.59	39.56

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
11.5	35.36	35.92	35.14
11.6	35.61	30.73	36.71
11.7	38.31	32.32	38.54
11.8	39.43	34.35	37.38
11.9	37.94	36.57	39.4
12	38.43	31.91	33.51
12.1	44.5	30.89	35.27
12.2	43.36	34.21	35.6
12.3	40.18	33.15	32.38
12.4	41.06	39.93	30.32
12.5	44.29	39.4	34.8
12.6	45.82	40.5	39.6
12.7	45.83	37.29	36.23
12.8	48.56	37.19	36.94
12.9	47.98	32.64	39.42
13	46.21	31.93	37.58
13.1	43.49	37.29	36
13.2	39.6	37.83	39.41
13.3	43.59	35.02	39.23
13.4	47.58	38.02	40.74
13.5	51.34	39.83	37.76
13.6	49.54	39.29	38.51
13.7	49.1	36.66	38.83

Appendix D DRILL RESISTANCE: MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.20)

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
13.8	44.79	37.01	34.35
13.9	40.57	36.73	38.58
14	42.05	32.91	40.45
14.1	40.46	31.91	40
14.2	39.44	36.44	41.03
14.3	40.55	38.72	39.67
14.4	42.65	36.2	39.84
14.5	44.03	35.56	43.4
14.6	38.27	39.48	41.52
14.7	40.36	42.69	42.24
14.8	45.3	41.98	39.77
14.9	45.21	38.34	38.35
15	41.02	32.8	39.48
15.1	38.86	36.17	43.98
15.2	44.83	35.53	45.94
15.3	43.58	35.51	43.99
15.4	41.35	35.8	41.1
15.5	46.56	33.78	43.25
15.6	52.04	37.96	46.17
15.7	45.78	39.61	43.4
15.8	42.91	38.92	42.95
15.9	43.87	37.96	48.29
16	45.28	39.06	41.98

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
16.1	42.35	40.01	39.55
16.2	40.9	44.01	37.86
16.3	42.12	47.28	36.11
16.4	44.32	46.35	39.07
16.5	43.18	43.49	37.81
16.6	43.3	48.17	40.05
16.7	46.03	41.67	40.86
16.8	42.99	35.4	41.76
16.9	41.22	34.09	43.89
17	48.66	35.07	46.42
17.1	49.17	34.66	42.3
17.2	45.56	40.02	40.93
17.3	46.6	41.13	38.13
17.4	43.28	42.6	42.12
17.5	47.03	41.79	42.01
17.6	47.02	37.21	42.44
17.7	47.09	38.92	43.23
17.8	48.6	41.79	42.71
17.9	47.14	43.99	39.24
18	49.52	47.04	42.83
18.1	51.14	41.49	48.25
18.2	53.61	39.22	50.89
18.3	47.69	40.87	45.03

Appendix D DRILL RESISTANCE: MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.20)

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
18.4	45.74	43.74	41.63
18.5	44.43	44	38.16
18.6	47.78	43.25	40.52
18.7	52.55	43.93	46.59
18.8	53.43	44.31	51.78
18.9	49.62	49.16	48.7
19	50.11	48.69	41.06
19.1	54.5	46.41	39.26
19.2	58.27	40.76	45.53
19.3	52.07	39.54	52.63
19.4	52.9	38.85	50.91
19.5	53.24	41.16	51.83
19.6	54.58	39.38	51.99
19.7	55.53	45.58	56.56
19.8	53.22	45.05	45.68
19.9	59.05	40.02	22.39
20	58.61	40.51	45.85
20.1	54.63	41.02	68.13
20.2	48.52	40.02	72.93
20.3	48.62	34.06	69.05
20.4	51.36	36.35	66.9
20.5	52.25	41.55	65.48
20.6	54.5	44.5	64.57

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
20.7	52.69	40.89	64.08
20.8	50.6	44.44	
20.9	49.88	49.62	
21	50.83	42.48	
21.1	54.61	42.67	
21.2	56.05	40.2	
21.3	57.02	36.51	
21.4	55.69	40.05	
21.5	52.68	44.1	
21.6	48.51	45.02	
21.7	43.8	39.88	
21.8	44.01	39.52	
21.9	49.63	41.05	
22	57.58	39.99	
22.1	60.57	37.45	
22.2	61.53	40.9	
22.3	58.09	38.52	
22.4	53.77	39.14	
22.5	55.76	41.39	
22.6	55.58	48.74	
22.7	52.27	49.55	
22.8	55.98	45.05	
22.9	56.96	43.7	

Appendix D DRILL RESISTANCE: MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.20)

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
23	58.67	44.7	
23.1	57	46.83	
23.2	53.46	48.38	
23.3	51.12	48.02	
23.4	55.76	44.84	
23.5	52.15	40.27	
23.6	51.33	37.71	
23.7	50.12	39.61	
23.8	53.22	40.59	
23.9	51.84	37.84	
24	53.17	41.71	
24.1	59.19	41.9	
24.2	56.08	39.62	
24.3	50.74	41.97	
24.4	51.62	37.19	
24.5	53.35	39.09	
24.6	56.6	34.12	
24.7	53.85	35.3	
24.8	57.11	35.81	
24.9	61.14	43.01	
25	63.53	43.94	
25.1	63.23	40.32	
25.2	62.54	42.97	

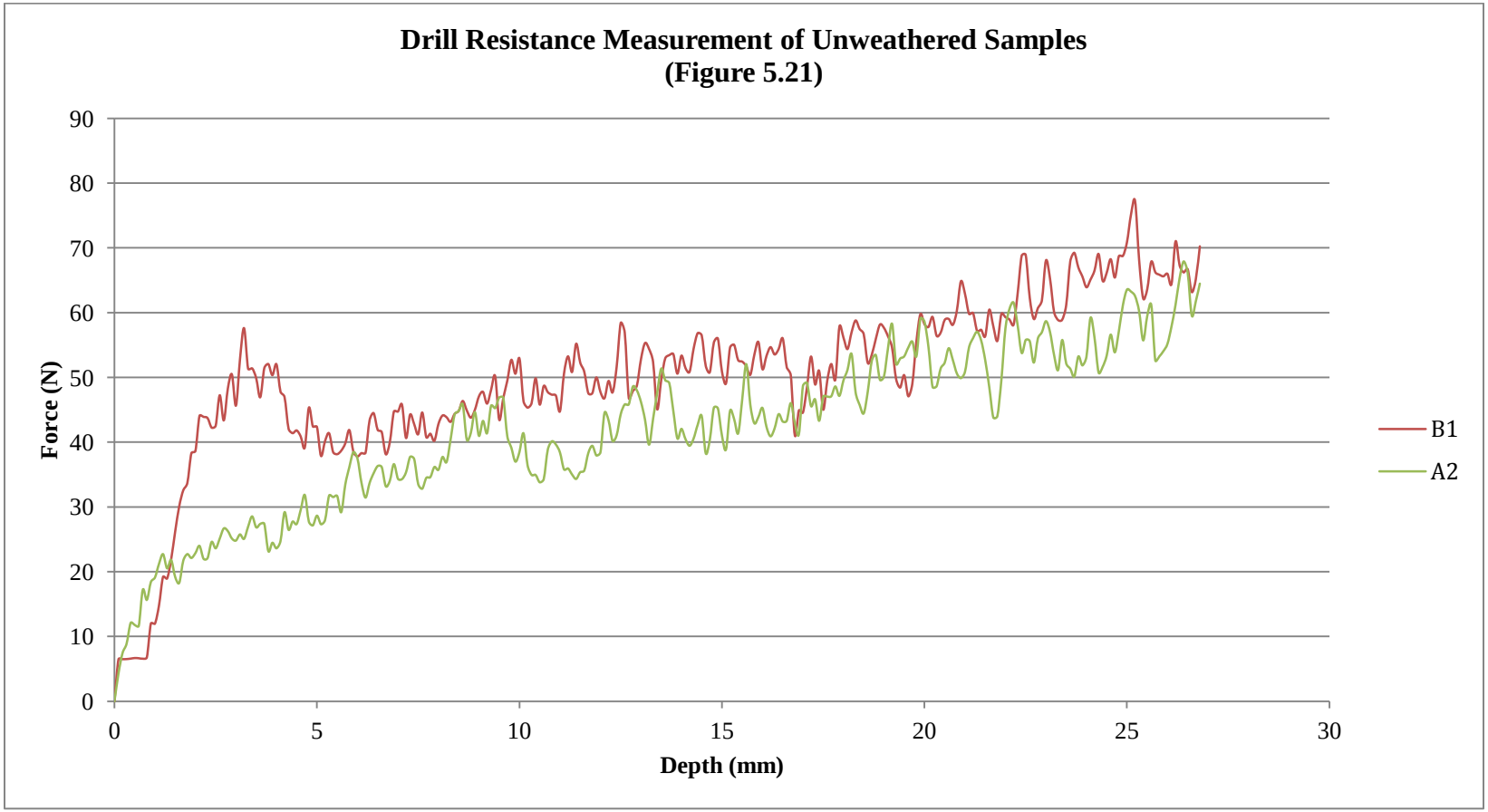
Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
25.3	60.21	43.13	
25.4	55.7	41.98	
25.5	59.43	48.11	
25.6	61.18	52.9	
25.7	52.6	45.1	
25.8	53.23	38.14	
25.9	54.05	39.88	
26	55.16	47.23	
26.1	57.85	45.65	
26.2	61.2	42.83	
26.3	65.3	46.74	
26.4	67.89	47.18	
26.5	66.12	50	
26.6	59.53	48.32	
26.7	61.72	48.25	
26.8	64.46	45.61	
26.9	67.54	40.96	
27	70.96	42.37	
27.1	65.29	46.67	
27.2	60.51	49.09	
27.3	56.44	48.02	
27.4	54.87	44.79	
27.5	59.47	46.6	

Appendix D DRILL RESISTANCE: MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.20)

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
27.6	59.35	47.39	
27.7	61.53	44.66	
27.8	64.24	50.45	
27.9	64.06	55.28	
28	58.96	50.38	
28.1	55.44	51.9	
28.2	57.14	52.65	
28.3	57.98	52.65	
28.4	60.98	50.72	
28.5	64.63	55.99	
28.6	65.16	58.32	
28.7	57.86	55.28	
28.8	52.95	54.02	
28.9	55.17	54.28	
29	52.96	49.76	
29.1	55.25	50.99	
29.2	48.93	56.6	
29.3	45.93	60	
29.4	50.14	58.14	
29.5	49.81		
29.6	51.35		
29.7	54.29		
29.8	53.11		

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
29.9	54.54		
30	57.33		

Appendix D DRILL RESISTANCE
7/32” carbide tipped bit
900 rpm
10 mm/min



Appendix D DRILL RESISTANCE MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.21)

Depth [mm]	Force [N]	
	Prosoco OH100 [A2]	Remmers KSE 300 E [B2]
0	0	0
0.1	4.3	6.49
0.2	7.44	6.5
0.3	8.89	6.52
0.4	12.09	6.59
0.5	11.79	6.68
0.6	11.63	6.65
0.7	17.21	6.58
0.8	15.65	6.77
0.9	18.41	12
1	19.1	11.98
1.1	21.21	14.79
1.2	22.72	19.21
1.3	20.52	18.95
1.4	21.83	21.88
1.5	19.19	26.22
1.6	18.28	30.12
1.7	21.71	32.58
1.8	22.72	33.7
1.9	22.12	38.3
2	22.88	38.65
2.1	23.99	44.06
2.2	22	43.9

Depth [mm]	Force [N]	
	Prosoco OH100 [A2]	Remmers KSE 300E [B2]
2.3	22.11	43.71
2.4	24.6	42.24
2.5	23.61	42.54
2.6	25.12	47.25
2.7	26.68	43.35
2.8	26.27	48.27
2.9	25.13	50.48
3	24.81	45.64
3.1	25.76	52.81
3.2	25.07	57.61
3.3	26.94	51.34
3.4	28.54	51.41
3.5	26.85	49.88
3.6	27.38	46.93
3.7	27.4	51.42
3.8	23.17	52.06
3.9	24.47	50.34
4	23.61	52.03
4.1	24.71	47.81
4.2	29.19	46.96
4.3	26.46	42.06
4.4	27.74	41.39
4.5	27.37	41.81

Appendix D DRILL RESISTANCE MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.21)

Depth [mm]	Force [N]	
	Prosoco OH100 [A2]	Remmers KSE 300 E [B2]
4.6	29.56	40.87
4.7	31.85	39.17
4.8	27.74	45.32
4.9	27.15	42.42
5	28.65	42.35
5.1	27.33	37.88
5.2	27.96	40.16
5.3	31.75	41.38
5.4	31.51	38.47
5.5	31.68	38.15
5.6	29.18	38.69
5.7	33.46	39.81
5.8	36.15	41.87
5.9	38.46	38.53
6	37.48	37.79
6.1	33.73	38.32
6.2	31.44	38.36
6.3	33.7	43.38
6.4	35.2	44.49
6.5	36.31	41.89
6.6	36.15	41.56
6.7	33.19	38.13
6.8	34.04	40.02

Depth [mm]	Force [N]	
	Prosoco OH100 [A2]	Remmers KSE 300E [B2]
6.9	36.61	44.72
7	34.35	44.71
7.1	34.29	45.8
7.2	35.35	40.64
7.3	37.72	44.27
7.4	37.4	42.8
7.5	33.52	41.23
7.6	32.81	44.59
7.7	34.48	40.77
7.8	34.6	41.31
7.9	36.16	40.21
8	35.73	42.81
8.1	37.71	44.11
8.2	36.92	43.85
8.3	40.41	43.13
8.4	44.26	44.37
8.5	44.79	44.82
8.6	45.82	46.36
8.7	40.38	44.9
8.8	41.43	43.78
8.9	44.64	44.99
9	40.96	47.07
9.1	43.28	47.77

Appendix D DRILL RESISTANCE MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.21)

Depth [mm]	Force [N]	
	Prosoco OH100 [A2]	Remmers KSE 300 E [B2]
9.2	41.37	45.95
9.3	45.62	48.07
9.4	45.24	50.21
9.5	46.89	43.46
9.6	46.85	46.79
9.7	40.92	49.47
9.8	39.14	52.71
9.9	36.99	50.56
10	38.47	52.92
10.1	41.37	46.34
10.2	36.45	45.33
10.3	34.94	46.01
10.4	34.93	49.87
10.5	33.8	45.8
10.6	34.29	48.68
10.7	38.84	47.72
10.8	40.12	47.33
10.9	39.63	47.19
11	38.41	44.76
11.1	35.8	50.56
11.2	35.94	53.25
11.3	35	50.83
11.4	34.32	55.19

Depth [mm]	Force [N]	
	Prosoco OH100 [A2]	Remmers KSE 300E [B2]
11.5	35.36	52.29
11.6	35.61	50.88
11.7	38.31	47.56
11.8	39.43	47.56
11.9	37.94	49.99
12	38.43	47.74
12.1	44.5	46.78
12.2	43.36	49.45
12.3	40.18	47.68
12.4	41.06	51.62
12.5	44.29	58.41
12.6	45.82	56.91
12.7	45.83	46.81
12.8	48.56	47.9
12.9	47.98	48.73
13	46.21	52.78
13.1	43.49	55.29
13.2	39.6	54.39
13.3	43.59	52.38
13.4	47.58	45.08
13.5	51.34	49.58
13.6	49.54	52.94
13.7	49.1	53.43

Appendix D DRILL RESISTANCE MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.21)

Depth [mm]	Force [N]	
	Prosoco OH100 [A2]	Remmers KSE 300 E [B2]
13.8	44.79	53.59
13.9	40.57	50.57
14	42.05	53.36
14.1	40.46	51.44
14.2	39.44	50.85
14.3	40.55	54.41
14.4	42.65	56.82
14.5	44.03	56.48
14.6	38.27	51.78
14.7	40.36	50.79
14.8	45.3	55.37
14.9	45.21	55.98
15	41.02	50.9
15.1	38.86	49.06
15.2	44.83	54.6
15.3	43.58	55.04
15.4	41.35	52.66
15.5	46.56	52.44
15.6	52.04	51.74
15.7	45.78	50.4
15.8	42.91	53.49
15.9	43.87	55.46
16	45.28	51.26

Depth [mm]	Force [N]	
	Prosoco OH100 [A2]	Remmers KSE 300E [B2]
16.1	42.35	53.32
16.2	40.9	54.67
16.3	42.12	53.54
16.4	44.32	54.37
16.5	43.18	56.02
16.6	43.3	51.56
16.7	46.03	50.3
16.8	42.99	41.04
16.9	41.22	44.9
17	48.66	44.57
17.1	49.17	48.49
17.2	45.56	53.22
17.3	46.6	48.91
17.4	43.28	51
17.5	47.03	45.01
17.6	47.02	49.48
17.7	47.09	52.07
17.8	48.6	49.67
17.9	47.14	57.83
18	49.52	56.15
18.1	51.14	54.37
18.2	53.61	56.95
18.3	47.69	58.79

Appendix D DRILL RESISTANCE MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.21)

Depth [mm]	Force [N]	
	Prosoco OH100 [A2]	Remmers KSE 300 E [B2]
18.4	45.74	57.45
18.5	44.43	56.69
18.6	47.78	52.24
18.7	52.55	53.51
18.8	53.43	55.96
18.9	49.62	58.14
19	50.11	57.65
19.1	54.5	56.34
19.2	58.27	54.61
19.3	52.07	49.75
19.4	52.9	48.42
19.5	53.24	50.35
19.6	54.58	47.09
19.7	55.53	48.99
19.8	53.22	55.45
19.9	59.05	59.76
20	58.61	58.21
20.1	54.63	57.79
20.2	48.52	59.33
20.3	48.62	56.43
20.4	51.36	56.9
20.5	52.25	58.87
20.6	54.5	59.02

Depth [mm]	Force [N]	
	Prosoco OH100 [A2]	Remmers KSE 300E [B2]
20.7	52.69	58.11
20.8	50.6	60.29
20.9	49.88	64.83
21	50.83	62.92
21.1	54.61	59.82
21.2	56.05	59.93
21.3	57.02	57.17
21.4	55.69	57.35
21.5	52.68	56.34
21.6	48.51	60.45
21.7	43.8	57.88
21.8	44.01	55.62
21.9	49.63	59.8
22	57.58	59.29
22.1	60.57	58.93
22.2	61.53	58.12
22.3	58.09	62.88
22.4	53.77	68.76
22.5	55.76	68.91
22.6	55.58	62.29
22.7	52.27	59.02
22.8	55.98	60.69
22.9	56.96	61.89

Appendix D DRILL RESISTANCE MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.21)

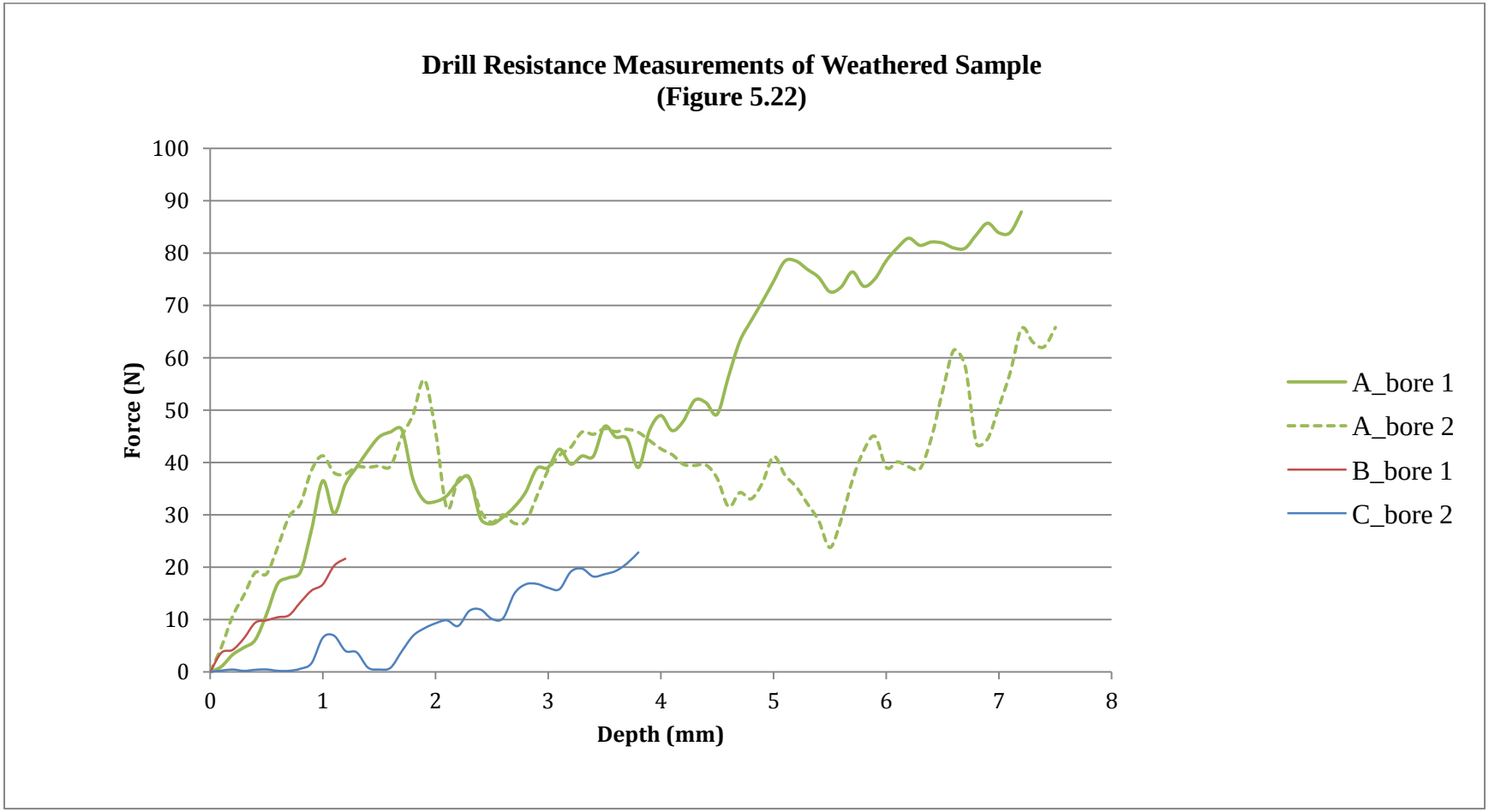
Depth [mm]	Force [N]	
	Prosoco OH100 [A2]	Remmers KSE 300 E [B2]
23	58.67	68.04
23.1	57	65.26
23.2	53.46	60.1
23.3	51.12	58.85
23.4	55.76	58.89
23.5	52.15	61.15
23.6	51.33	67.89
23.7	50.12	69.24
23.8	53.22	66.97
23.9	51.84	65.56
24	53.17	63.91
24.1	59.19	65.09
24.2	56.08	66.5
24.3	50.74	69.05
24.4	51.62	64.9
24.5	53.35	66.14
24.6	56.6	68.24
24.7	53.85	65.4
24.8	57.11	68.7
24.9	61.14	68.75
25	63.53	70.85
25.1	63.23	75.14
25.2	62.54	77.25

Depth [mm]	Force [N]	
	Prosoco OH100 [A2]	Remmers KSE 300E [B2]
25.3	60.21	68.16
25.4	55.7	62.19
25.5	59.43	63.57
25.6	61.18	67.86
25.7	52.6	66.23
25.8	53.23	65.85
25.9	54.05	65.6
26	55.16	65.99
26.1	57.85	64.41
26.2	61.2	71
26.3	65.3	67.29
26.4	67.89	66.2
26.5	66.12	66.69
26.6	59.53	63.17
26.7	61.72	65.13
26.8	64.46	70.23
26.9	67.54	
27	70.96	
27.1	65.29	
27.2	60.51	
27.3	56.44	
27.4	54.87	
27.5	59.47	

Appendix D DRILL RESISTANCE MEASUREMENT OF UNWEATHERED SAMPLES (FIGURE 5.21)

	Force [N]	
Depth [mm]	Prosoco OH100 [A2]	Remmers KSE 300 E [B2]
27.6	59.35	
27.7	61.53	
27.8	64.24	
27.9	64.06	
28	58.96	
28.1	55.44	
28.2	57.14	
28.3	57.98	
28.4	60.98	
28.5	64.63	
28.6	65.16	
28.7	57.86	
28.8	52.95	
28.9	55.17	
29	52.96	
29.1	55.25	
29.2	48.93	
29.3	45.93	
29.4	50.14	
29.5	49.81	
29.6	51.35	
29.7	54.29	
29.8	53.11	
30	54.54	

Appendix D DRILL RESISTANCE
1/8” carbide tipped bit
900 rpm
10 mm/min



Appendix D DRILL RESISTANCE MEASUREMENTS OF WEATHERED SAMPLE (FIGURE 5.22)

Depth [mm]	Force [N]			
	A_bore 1	A_bore 2	B_bore 1	C_bore 2
0	0	0	0	0
0.1	1.03	4.75	3.68	0.26
0.2	3.3	10.69	4.22	0.45
0.3	4.66	14.69	6.43	0.2
0.4	6.11	18.99	9.4	0.4
0.5	11	18.72	9.86	0.47
0.6	16.86	23.91	10.46	0.21
0.7	18.01	29.67	10.83	0.21
0.8	19.02	32.11	13.29	0.6
0.9	27.19	38.58	15.56	1.68
1	36.52	41.31	16.73	6.54
1.1	30.27	38.06	20.29	6.91
1.2	35.92	37.83	21.65	4.02
1.3	39.12	39.2	20.56	3.74
1.4	42.24	39.09	13.15	0.82
1.5	44.89	39.38	24.81	0.46
1.6	45.83	39.28	46.26	0.78
1.7	46.33	45.03	67.77	3.92
1.8	36.81	49.16		6.89
1.9	32.71	55.81		8.33
2	32.54	45.94		9.29
2.1	33.64	31.3		9.86

Appendix D DRILL RESISTANCE MEASUREMENTS OF WEATHERED SAMPLE (FIGURE 5.22)

Depth [mm]	Force [N]		
	A_bore 1	A_bore 2	C_bore 2
2.2	36.23	36.71	8.78
2.3	37.16	36.98	11.67
2.4	29.29	30.78	11.91
2.5	28.27	28.59	10.13
2.6	29.59	30.03	10.28
2.7	31.53	28.41	14.98
2.8	34.34	28.73	16.74
2.9	38.88	33.64	16.82
3	39.05	38.59	16.07
3.1	42.55	41.4	15.81
3.2	39.7	42.95	19.14
3.3	41.25	45.85	19.73
3.4	41.17	45.42	18.23
3.5	46.9	46.51	18.67
3.6	44.86	45.92	19.3
3.7	44.58	46.37	20.75
3.8	39.07	45.78	22.84
3.9	46.18	44.21	19.6
4	48.98	42.63	10.19
4.1	46.1	41.53	27.6
4.2	47.93	39.67	42
4.3	51.88	39.47	55.98
4.4	51.45	39.55	72.25
4.5	49.22	36.96	83.84

Appendix D DRILL RESISTANCE MEASUREMENTS OF WEATHERED SAMPLE (FIGURE 5.22)

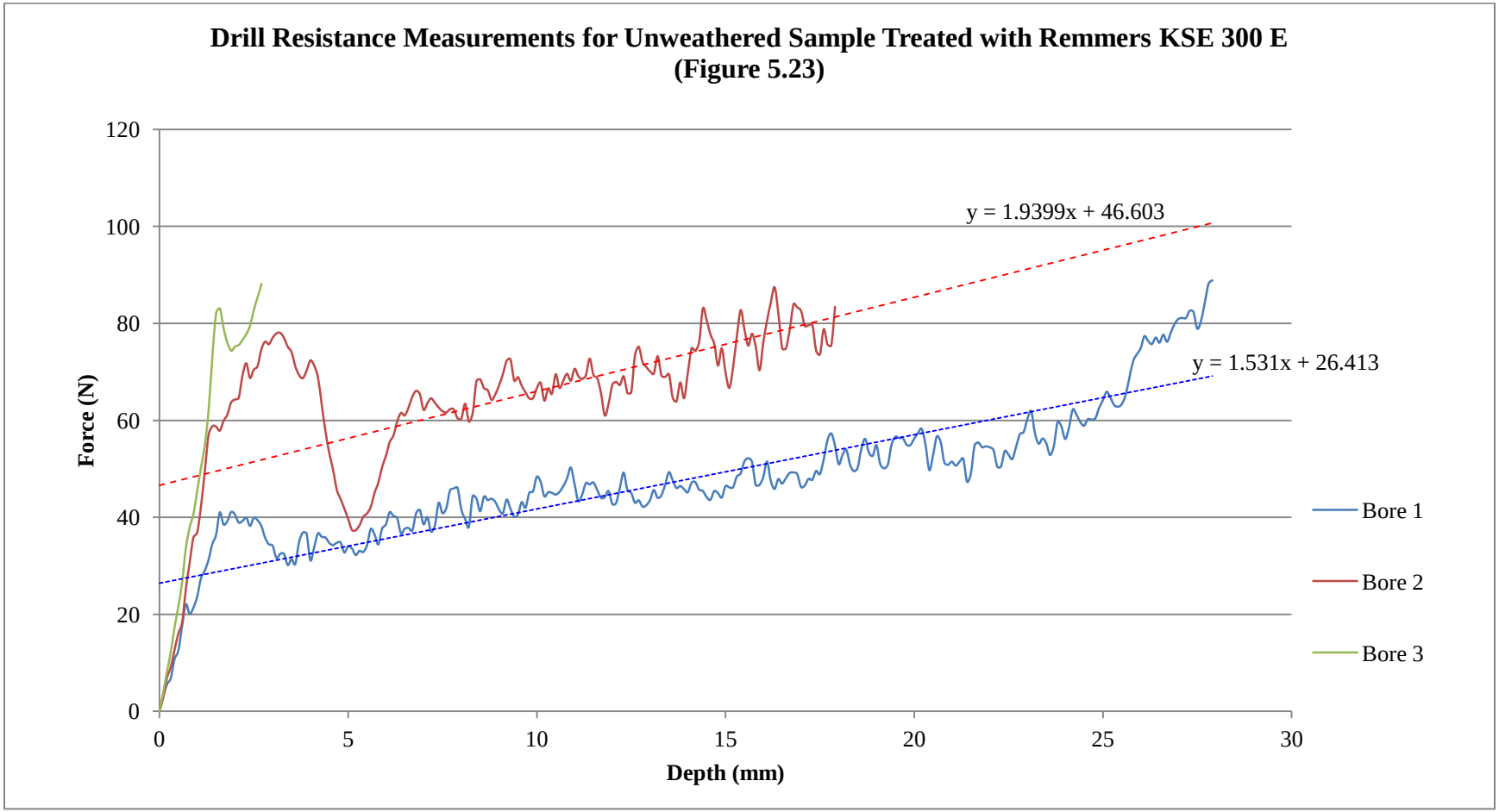
Depth [mm]	Force [N]	
	A_bore 1	A_bore 2
4.6	56.4	31.58
4.7	63.13	34.27
4.8	67.04	33.07
4.9	70.7	36.12
4.9	74.6	41.18
5	78.47	37.63
5.1	78.5	35.38
5.2	76.91	32.13
5.3	75.4	28.89
5.4	72.63	23.78
5.5	73.52	29.15
5.6	76.42	36.72
5.7	73.68	42.32
5.8	75.08	45.01
5.9	78.53	39.07
6	81.03	40.15
6.1	82.85	39.18
6.2	81.49	38.86
6.3	82.13	44.75
6.4	81.93	53.7
6.5	80.99	61.53
6.6	80.95	58.38

Appendix D DRILL RESISTANCE MEASUREMENTS OF WEATHERED SAMPLE (FIGURE 5.22)

Depth [mm]	Force [N]	
	A_bore 1	A_bore 2
6.7	83.5	43.62
6.8	85.73	44.59
7	85.73	50.72
7.1	83.9	57.28
7.2	83.94	65.63
7.3	87.87	63.04
7.4		62.14
7.4		65.85
7.5		35.98
7.4		50.72
7.5		57.28
7.6		65.63

Appendix D DRILL RESISTANCE

7/32” carbide tipped bit
900 rpm
10 mm/min



Appendix D DRILL RESISTANCE MEASUREMENTS FOR UNWEATHERED … WITH REMMERS KSE 300 E (FIGURE 5.23)

Depth [mm]	Force [N]		
	Bore 1	Bore 2	Bore 3
0	0	0	0
0.1	3	2.83	3.86
0.2	5.54	6.88	8.16
0.3	6.76	9.07	12.18
0.4	10.77	12.62	17.31
0.5	12.42	15.99	21.56
0.6	17.5	18.21	26.54
0.7	22.03	25.15	33.7
0.8	20.06	30.58	37.94
0.9	21.34	35.81	40.68
1	23.61	36.87	45.49
1.1	27.4	42.16	50.29
1.2	28.97	49.32	54.83
1.3	31.16	56.9	62.07
1.4	34.46	58.79	73.11
1.5	36.32	58.71	82.16
1.6	41.01	57.9	83.07
1.7	38.52	59.9	78.84
1.8	39.21	61.2	75.92
1.9	41.09	63.7	74.35
2	40.6	64.33	75.22
2.1	38.92	64.65	75.54
2.2	39.23	69.19	76.61
2.3	39.95	71.81	77.81
2.4	38.22	68.75	79.61
2.5	39.89	70.48	82.87
2.6	39.41	71.18	85.49
2.7	38.24	74.63	88.13
2.8	35.8	76.25	
2.9	34.43	75.72	
3	34.14	77.05	
3.1	31.59	77.95	
3.2	32.45	78.08	
3.3	32.45	77.05	
3.4	30.14	75.2	
3.5	31.38	74.12	
3.6	30.36	71.16	
3.7	34.89	69.38	
3.8	36.84	68.71	
3.9	36.63	70.31	
4	31.09	72.38	
4.1	33.81	71.31	
4.2	36.68	68.89	
4.3	35.97	63.33	
4.4	35.83	57.72	
4.5	34.73	53.27	

Appendix D DRILL RESISTANCE MEASUREMENTS FOR UNWEATHERED … WITH REMMERS KSE 300 E (FIGURE 5.23)

Depth [mm]	Force [N]	
	Bore 1	Bore 2
4.6	34.28	49.85
4.7	34.74	45.68
4.8	34.82	43.8
4.9	32.74	41.79
5	33.99	39.69
5.1	33.59	37.41
5.2	32.22	37.34
5.3	33.09	38.34
5.4	32.84	40.11
5.5	34.22	40.8
5.6	37.59	42.17
5.7	36.47	45.06
5.8	34.39	47.18
5.9	37.69	50.39
6	38.49	52.64
6.1	41.06	55.51
6.2	40.27	56.88
6.3	39.82	59.79
6.4	36.69	61.55
6.5	37.64	61.03
6.6	37.8	62.64
6.7	37.25	64.88
6.8	40.8	66.11

Depth [mm]	Force [N]	
	Bore 1	Bore 2
6.9	41.5	65.42
7	38.55	62.17
7.1	40.01	63.57
7.2	33.99	33.99
7.3	33.59	33.59
7.4	45.95	62.26
7.5	46.08	60.45
7.6	41.6	60.37
7.7	39.68	63.45
7.8	38.03	59.74
7.9	44.38	61.51
8	43.9	68.13
8.1	41.24	68.46
8.2	44.28	66.65
8.3	43.56	66.22
8.4	43.84	64.23
8.5	43.16	65.4
8.6	41.59	67.26
8.7	40.8	69.56
8.8	43.66	72.3
8.9	41.79	72.62
9	40.1	68.23
9.1	40.58	68.92

Appendix D DRILL RESISTANCE MEASUREMENTS FOR UNWEATHERED … WITH REMMERS KSE 300 E (FIGURE 5.23)

Depth [mm]	Force [N]	
	Bore 1	Bore 2
9.2	43.12	67.13
9.3	41.95	65.78
9.4	45.04	64.54
9.5	45.36	64.63
9.6	43.12	67.13
9.7	41.95	65.78
9.8	45.04	64.54
9.9	45.36	64.63
10	48.37	66.65
10.1	47.37	67.77
10.2	44.35	64.08
10.3	45.17	66.63
10.4	45.05	65.51
10.5	44.68	69.53
10.6	45.23	66.69
10.7	46.42	68.21
10.8	47.99	69.63
10.9	50.27	68.19
11	46.88	70.65
11.1	43.31	69.14
11.2	44.64	68.58
11.3	47.05	69.36
11.4	46.77	72.77

Depth [mm]	Force [N]	
	Bore 1	Bore 2
11.5	47.19	69.35
11.6	45.65	68.72
11.7	44.03	65.62
11.8	44.14	61.01
11.9	45.44	63.47
12	42.75	67.35
12.1	42.93	67.96
12.2	46.01	67.31
12.3	49.23	69.09
12.4	45.6	65.67
12.5	45.07	65.82
12.6	43.01	73.5
12.7	43.51	75.21
12.8	42.22	72.03
12.9	42.48	71.03
13	43.56	70.11
13.1	45.63	69.67
13.2	44.03	73.26
13.3	44.52	69.29
13.4	46.69	68.97
13.5	49.3	69.52
13.6	47.65	64.66
13.7	46.04	63.94

Appendix D DRILL RESISTANCE MEASUREMENTS FOR UNWEATHERED … WITH REMMERS KSE 300 E (FIGURE 5.23)

Depth [mm]	Force [N]	
	Bore 1	Bore 2
13.8	46.46	67.85
13.9	45.83	64.58
14	45.15	69.86
14.1	47.12	74.87
14.2	47.25	74.32
14.3	45.71	76.22
14.4	45.42	83.14
14.5	44.17	80.64
14.6	43.59	77.7
14.7	45.4	75.81
14.8	45	71.31
14.9	44.06	74.89
15	46.43	69.81
15.1	46.18	66.72
15.2	46.18	71.05
15.3	48.41	77.43
15.4	49.02	82.78
15.5	51.52	78.75
15.6	52.19	75.41
15.7	51.52	77.88
15.8	46.68	75.17
15.9	46.69	70.33
16	48.27	76.15
16.1	51.51	80.64

Depth [mm]	Force [N]	
	Bore 1	Bore 2
16.2	47.51	84.44
16.3	45.85	87.47
16.4	47.9	81.99
16.5	46.95	74.88
16.6	48.08	74.87
16.7	49.14	78.75
16.8	49.25	83.99
16.9	48.92	83.31
17	46.27	82.62
17.1	46.57	79.48
17.2	47.92	79.67
17.3	47.73	79.69
17.4	49.57	74.36
17.5	48.9	73.63
17.6	51.86	78.84
17.7	55.86	75.67
17.8	57.32	75.47
17.9	54.86	83.43
18	50.95	
18.1	52.85	
18.2	53.96	
18.3	50.89	
18.4	49.52	
18.5	50.18	

Appendix D DRILL RESISTANCE MEASUREMENTS FOR UNWEATHERED … WITH REMMERS KSE 300 E (FIGURE 5.23)

Depth [mm]	Force [N] Bore 1	Depth [mm]	Force [N] Bore 1	Depth [mm]	Force [N] Bore 1
18.6	54.13	20.8	51.28	23.1	61.89
18.7	56.18	20.9	50.84	23.2	57.31
18.8	53.36	21	51.48	23.3	55.17
18.9	52.67	21.1	50.65	23.4	56.25
19	54.88	21.2	51.44	23.5	55.26
19.1	50.99	21.3	52.1	23.6	52.84
19.1	50.99	21.4	47.33	23.7	54.7
19.2	50.09	21.5	48.9	23.8	59.62
19.3	50.81	21.6	54.84	23.9	58.76
19.4	55	21.7	55.43	24	56.16
19.5	56.61	21.8	54.46	24.1	58.43
19.6	56.34	21.9	54.64	24.2	62.22
19.7	56.32	22	54.43	24.3	61.18
19.8	54.96	22.1	53.9	24.4	59.66
19.9	54.92	22.2	50.48	24.5	58.89
20	56.2	22.3	50.5	24.6	60.23
20.1	57.37	22.4	53.66	24.7	60.16
20.2	58.24	22.5	52.91	24.8	60.43
20.3	54.99	22.6	52.02	24.9	62.58
20.4	49.73	22.7	54.57	25	64.16
20.5	52.83	22.8	57.15	25.1	65.9
20.6	56.71	22.9	57.59	25.2	64.65
20.7	55.61	23	60.28	25.3	63.14

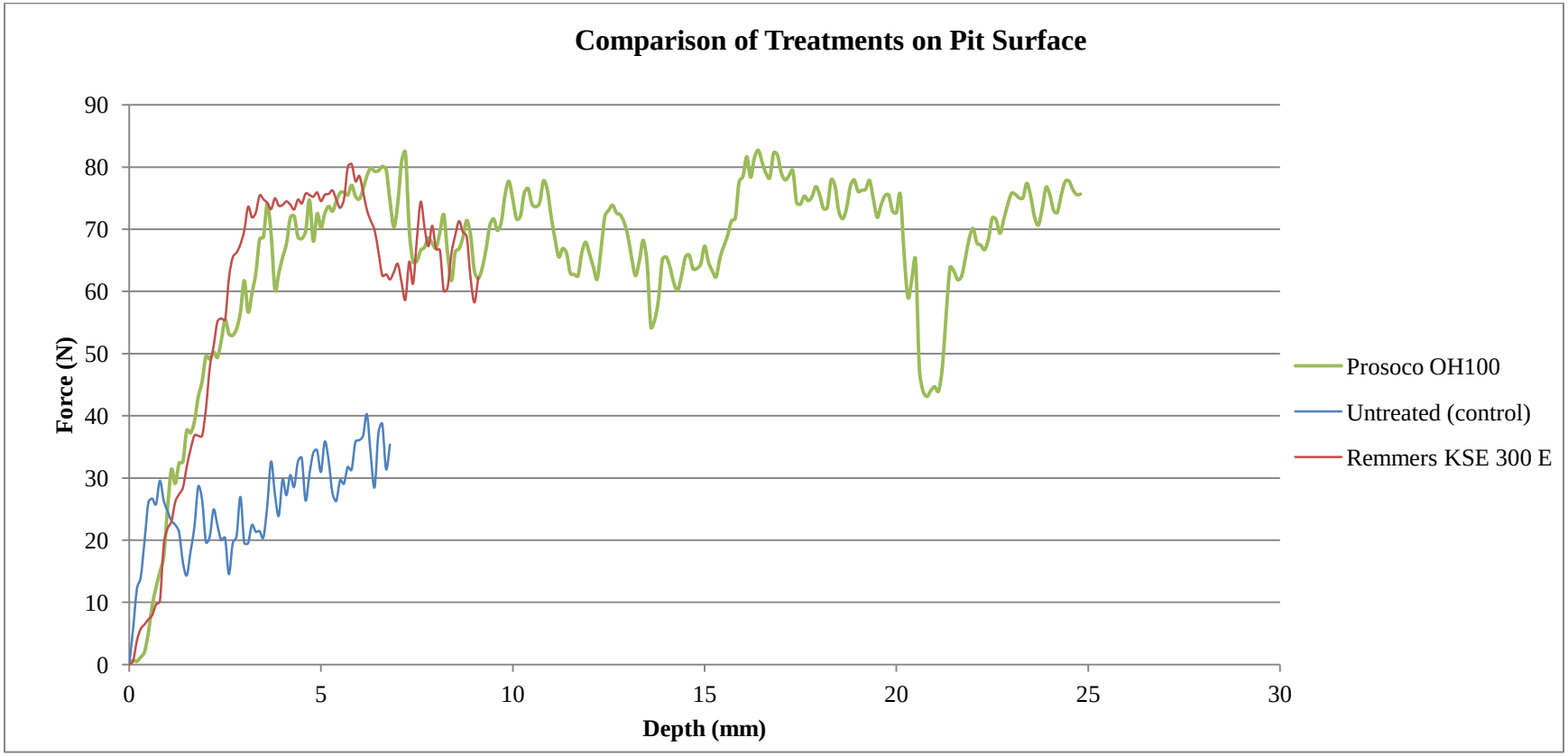
Appendix D DRILL RESISTANCE MEASUREMENTS FOR UNWEATHERED … WITH REMMERS KSE 300 E (FIGURE 5.23)

Depth [mm]	Force [N] Bore 1
25.4	62.82
25.5	63.33
25.6	65.21
25.7	68.7
25.8	72.16
25.9	73.63
26	74.85
26.1	77.36
26.2	76.36
26.3	75.73
26.4	77.08
26.5	76.03
26.6	77.67
26.7	76.21
26.8	78.09
26.9	79.89
27	80.91
27.1	81.13
27.2	81.11
27.3	82.61
27.4	82.35
27.5	78.9

Depth [mm]	Force [N] Bore 1
27.6	80.48
27.7	84.3
27.8	88.19
27.9	88.88

Appendix D DRILL RESISTANCE

3mm carbide tipped bit
600 rpm
10 mm/min



Appendix D DRILL RESISTANCE COMPARISON OF TREATMENTS ON PIT SURFACE

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
0	0	0	0
0.1	0.68	0.58	5.64
0.2	0.55	3.83	12.18
0.3	1.21	5.74	14.02
0.4	2.04	6.47	19.93
0.5	5.17	7.28	26.09
0.6	9.48	7.96	26.7
0.7	12.44	9.67	25.8
0.8	14.91	10.21	29.58
0.9	17.41	19.31	26.37
1	25.16	21.88	24.68
1.1	31.38	23	23.16
1.2	29.12	26.15	22.47
1.3	32.42	27.41	21.3
1.4	32.63	28.43	16.47
1.5	37.7	31.81	14.33
1.6	37.26	34.63	18.23
1.7	39.09	36.84	22.1
1.8	43.08	36.78	28.64
1.9	45.49	36.75	26.53
2	49.61	41.14	19.72
2.1	49.14	47.72	20.53
2.2	50.25	51.2	24.94

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
	49.42	55.16	22.42
2.3	52.12	55.66	20.01
2.4	55.49	55.45	20.39
2.5	53.18	62.14	14.56
2.6	52.97	65.49	19.55
2.7	54.02	66.24	20.66
2.8	56.7	67.59	26.96
2.9	61.76	69.81	19.58
3	56.67	73.61	19.5
3.1	59.73	71.89	22.45
3.2	62.92	72.65	21.38
3.3	68.41	75.42	21.46
3.4	68.81	74.79	20.44
3.5	74.11	74.24	25.53
3.6	69.2	73.23	32.67
3.7	60.29	74.97	27.42
3.8	62.96	73.77	23.91
3.9	65.51	73.92	29.74
4	67.76	74.47	27.24
4.1	71.9	73.94	30.47
4.2	72.13	73.16	28.58
4.3	68.76	74.77	32.67
4.4	68.51	74.13	33.24

Appendix D DRILL RESISTANCE COMPARISON OF TREATMENTS ON PIT SURFACE

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
2.3	49.42	55.16	22.42
2.4	52.12	55.66	20.01
2.5	55.49	55.45	20.39
2.6	53.18	62.14	14.56
2.7	52.97	65.49	19.55
2.8	54.02	66.24	20.66
2.9	56.7	67.59	26.96
3	61.76	69.81	19.58
3.1	56.67	73.61	19.5
3.2	59.73	71.89	22.45
3.3	62.92	72.65	21.38
3.4	68.41	75.42	21.46
3.5	68.81	74.79	20.44
3.6	74.11	74.24	25.53
3.7	69.2	73.23	32.67
3.8	60.29	74.97	27.42
3.9	62.96	73.77	23.91
4	65.51	73.92	29.74
4.1	67.76	74.47	27.24
4.2	71.9	73.94	30.47
4.3	72.13	73.16	28.58
4.4	68.76	74.77	32.67
4.5	68.51	74.13	33.24

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
4.6	69.71	75.73	26.39
4.7	74.72	75.5	30.62
4.8	68.09	75.21	34.04
4.9	72.53	75.91	34.49
5	70.26	74.51	30.98
5.1	72.58	75.55	35.87
5.2	73.7	75.66	32.89
5.3	72.92	76.25	27.61
5.4	74.54	74.73	26.3
5.5	75.9	73.43	29.63
5.6	75.94	74.82	29.09
5.7	75.54	80.07	31.79
5.8	77.1	80.47	31.32
5.9	75.29	77.7	35.84
6	74.88	78.56	36.09
6.1	76.52	75.93	36.8
6.2	78.68	73.03	40.25
6.3	79.84	71.3	33.7
6.4	79.33	69.77	28.51
6.5	79.44	66.24	37.29
6.6	80.13	62.53	38.74
6.7	79.59	62.76	31.43
6.8	74.46	61.92	35.38

Appendix D DRILL RESISTANCE COMPARISON OF TREATMENTS ON PIT SURFACE

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
4.6	69.71	75.73	26.39
4.7	74.72	75.5	30.62
4.8	68.09	75.21	34.04
4.9	72.53	75.91	34.49
5	70.26	74.51	30.98
5.1	72.58	75.55	35.87
5.2	73.7	75.66	32.89
5.3	72.92	76.25	27.61
5.4	74.54	74.73	26.3
5.5	75.9	73.43	29.63
5.6	75.94	74.82	29.09
5.7	75.54	80.07	31.79
5.8	77.1	80.47	31.32
5.9	75.29	77.7	35.84
6	74.88	78.56	36.09
6.1	76.52	75.93	36.8
6.2	78.68	73.03	40.25
6.3	79.84	71.3	33.7
6.4	79.33	69.77	28.51
6.5	79.44	66.24	37.29
6.6	80.13	62.53	38.74
6.7	79.59	62.76	31.43
6.8	74.46	61.92	35.38

Depth [mm]	Force [N]		
	Prosoco OH100	Remmers KSE 300 E	Untreated (control)
6.9	70.39	63.12	
7	74.13	64.43	
7.1	80.87	61.49	
7.2	82.39	58.66	
7.3	69.98	64.76	
7.4	64.74	61.24	
7.5	64.89	68.41	
7.6	66.62	74.42	
7.7	67.14	70.24	
7.8	68.62	67.27	
7.9	67.71	70.55	
8	67.03	66.77	
8.1	69.54	66.63	
8.2	72.35	60.1	
8.3	66.17	60.61	
8.4	61.75	66.1	
8.5	66.38	69.01	
8.6	66.87	71.3	
8.7	68.71	69.53	
8.8	71.45	68.78	
8.9	68.98	62.15	
9	63.23	58.21	
9.1	62.1	62.26	

Appendix D DRILL RESISTANCE COMPARISON OF TREATMENTS ON PIT SURFACE

Depth [mm]	Force [N] Prosoco OH100	Depth [mm]	Force [N] Prosoco OH100	Depth [mm]	Force [N] Prosoco OH100
9.2	63.73	11.6	62.75	13.9	65.18
9.3	66.73	11.7	62.52	14	65.56
9.4	70.6	11.8	66.25	14.1	63.9
9.5	71.69	11.9	67.95	14.2	61.36
9.6	69.84	12	66.06	14.3	60.2
9.7	71.14	12.1	63.94	14.4	62.61
9.8	75.6	12.2	62	14.5	65.56
9.9	77.73	12.3	66.84	14.6	65.86
10	74.82	12.4	72.09	14.7	63.66
10.1	71.65	12.5	73.07	14.8	63.72
10.2	72.12	12.6	73.9	14.9	64.43
10.3	75.9	12.7	72.66	15	67.33
10.4	76.58	12.8	72.34	15.1	64.77
10.5	74.08	12.9	71.17	15.2	63.34
10.6	73.62	13	68.92	15.3	62.37
10.7	74.26	13.1	65.36	15.4	65.35
10.8	77.81	13.2	62.55	15.5	67.29
10.9	76.42	13.3	64.97	15.6	69.01
11	72.07	13.4	68.24	15.7	71.38
11.1	68.46	13.5	64.66	15.8	71.77
11.2	65.57	13.6	54.29	15.9	77.63
11.3	66.93	13.7	55.44	16	78.49
11.4	66.19	13.8	58.84	16.1	81.69
11.5	62.93	13.9	65.18	16.2	78.36

Appendix D DRILL RESISTANCE COMPARISON OF TREATMENTS ON PIT SURFACE

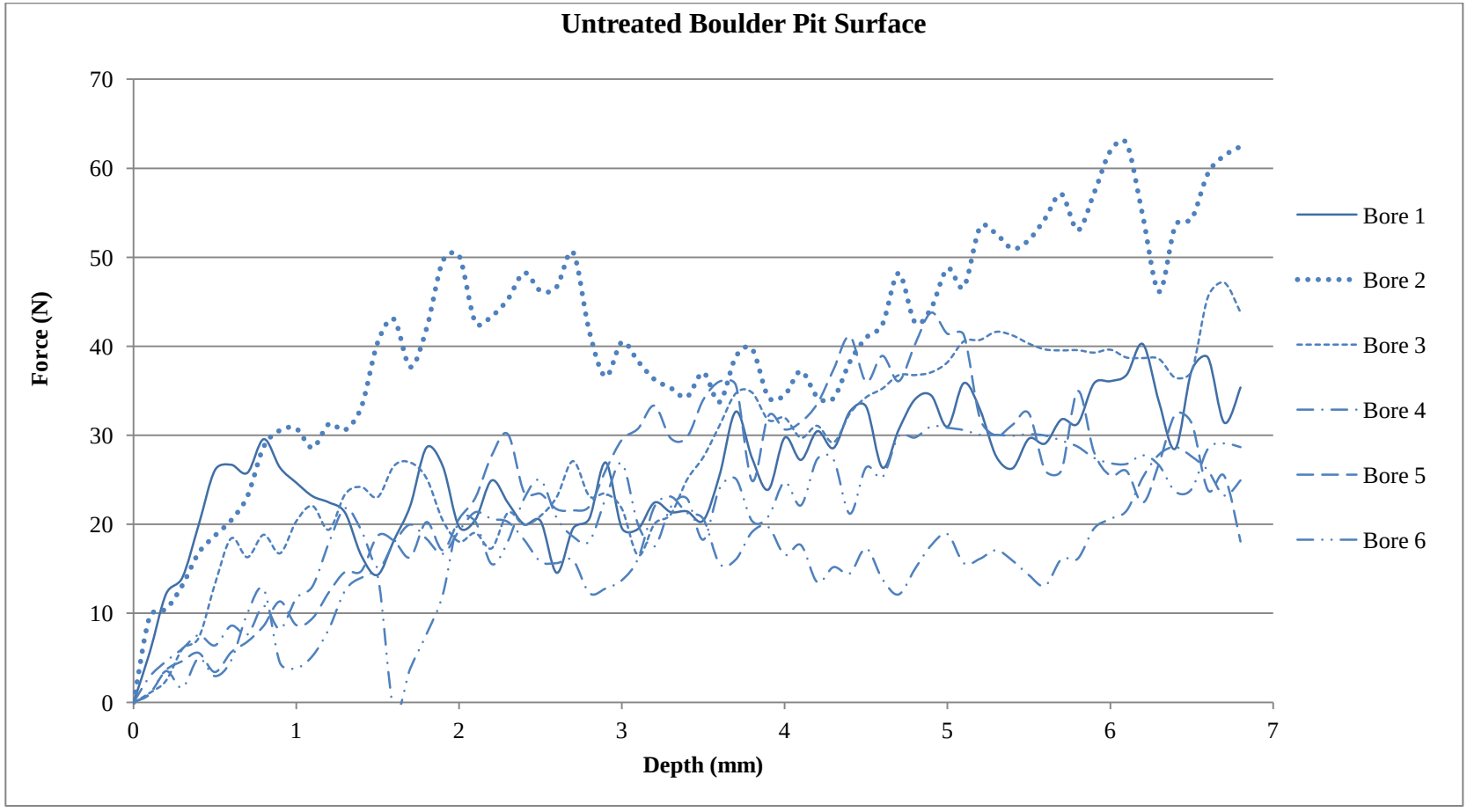
Depth [mm]	Force [N] Prosoco OH100	Depth [mm]	Force [N] Prosoco OH100	Depth [mm]	Force [N] Prosoco OH100
16.3	81.55	18.7	73.35	21.1	43.99
16.4	82.73	18.8	76.92	21.2	47.88
16.5	80.82	18.9	77.98	21.3	56.49
16.6	79.03	19	76.13	21.4	63.9
16.7	78.31	19.1	76.3	21.5	63.27
16.8	82.28	19.2	76.47	21.6	61.9
16.9	81.96	19.3	77.88	21.7	62.46
17	79.06	19.4	74.9	21.8	65.35
17.1	77.95	19.5	71.93	21.9	68.59
17.2	78.62	19.6	73.87	22	70.15
17.3	79.45	19.7	75.39	22.1	67.81
17.4	74.27	19.8	75.52	22.2	67.48
17.5	74.05	19.9	72.96	22.3	66.73
17.6	75.35	20	72.72	22.4	68.43
17.7	74.62	20.1	75.62	22.5	71.83
17.8	75.24	20.2	66.21	22.6	71.55
17.9	76.87	20.3	59.04	22.7	69.35
18	75.56	20.4	61.79	22.8	71.62
18.1	73.33	20.5	65.08	22.9	73.93
18.2	73.52	20.6	47.47	23	75.79
18.3	77.98	20.7	43.87	23.1	75.63
18.4	76.98	20.8	43.12	23.2	75.07
18.5	72.84	20.9	44.1	23.3	75.07
18.6	71.72	21	44.69	23.4	77.41

Appendix D DRILL RESISTANCE COMPARISON OF TREATMENTS ON PIT SURFACE

Depth [mm]	Force [N] Prosoco OH100
23.5	75.39
23.6	72
23.7	70.68
23.8	73.26
23.9	76.74
24	75.57
24.1	73.04
24.2	72.77
24.3	75.55
24.4	77.7
24.5	77.77
24.6	76.41
24.7	75.59
24.8	75.68

Appendix D DRILL RESISTANCE ON UNTREATED BOULDER PIT SURFACE

3mm carbide tipped bit
600 rpm
10 mm/min



Appendix D DRILL RESISTANCE ON UNTREATED BOULDER PIT SURFACE

	Force [N]					
Depth [mm]	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5	Bore 6
0	0	0	0	0	0	0
0.1	5.64	9.65	1.07	2.91	1.01	0.91
0.2	12.18	10.47	2.45	4.61	3.64	3.51
0.3	14.02	13.15	6	6.03	4.64	1.64
0.4	19.93	16.79	7.24	7.55	5.56	4.94
0.5	26.09	18.73	13.28	6.4	3.41	2.94
0.6	26.7	20.46	18.43	8.61	5.63	4.71
0.7	25.8	23.16	16.31	7.63	6.83	10
0.8	29.58	28.72	18.84	10.83	8.61	12.67
0.9	26.37	30.56	16.75	8.24	11.34	4.42
1	24.68	30.75	20.36	11.69	8.68	3.83
1.1	23.16	28.59	22.07	13.05	9.46	5.22
1.2	22.47	31.26	19.4	17.91	12.36	8.23
1.3	21.3	30.6	23.39	21.8	14.66	12.55
1.4	16.47	33.19	24.2	19.29	14.77	13.99
1.5	14.33	40.44	23.06	15.14	18.72	14.16
1.6	18.23	43.03	26.57	17.93	18.14	-0.94
1.7	22.1	37.67	26.96	19.97	16.29	3.8
1.8	28.64	42	25.18	18.36	20.25	7.67
1.9	26.53	49.58	20.44	16.68	17.1	12.12
2	19.72	50.17	18.06	19.27	20.61	20.61
2.1	20.53	42.66	19.04	21.36	22.99	20.3
2.2	24.94	43.37	17.31	20.6	27.72	15.53

Appendix D DRILL RESISTANCE ON UNTREATED BOULDER PIT SURFACE

Depth [mm]	Force [N]					
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5	Bore 6
2.3	22.42	45.29	21.31	20.26	30.11	18.1
2.4	20.01	48.26	19.96	18.25	23.58	22.9
2.5	20.39	46.22	20.96	15.81	23.43	24.96
2.6	14.56	46.69	23.09	15.64	21.7	20.71
2.7	19.55	50.54	27.11	15.95	21.56	18.61
2.8	20.66	41.66	23.17	12.27	22.01	18.09
2.9	26.96	36.6	23.45	12.79	26.05	22.88
3	19.58	40.47	21.76	13.72	29.49	26.83
3.1	19.5	38.29	16.51	16.18	30.76	19.93
3.2	22.45	36.27	20.06	21.98	33.32	17.5
3.3	21.38	35.31	21.12	23.11	29.66	21.93
3.4	21.46	34.31	25.03	21.28	29.8	22.88
3.5	20.44	37.04	27.56	20.6	33.99	18.26
3.6	25.53	33.74	31.12	15.57	36.04	24.01
3.7	32.67	38.83	34.73	16.05	35.62	25.1
3.8	27.42	39.69	34.81	19.14	24.87	20.36
3.9	23.91	34.28	31.73	19.68	32.18	20.9
4	29.74	34.52	31.98	16.57	30.65	24.73
4.1	27.24	37.21	29.73	17.66	31.49	22.12
4.2	30.47	34.32	31.08	13.5	33.54	27.32
4.3	28.58	34.17	29.21	15.19	37.38	27.27
4.4	32.67	38.24	32.44	14.47	41.11	21.18
4.5	33.24	40.96	34.28	17.3	36	26.37

Appendix D DRILL RESISTANCE ON UNTREATED BOULDER PIT SURFACE

	Force [N]					
Depth [mm]	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5	Bore 6
4.6	26.39	42.44	35.26	13.85	38.92	25.27
4.7	30.62	48.21	36.77	12.12	36.07	29.89
4.8	34.04	42.7	36.78	14.98	40.18	29.74
4.9	34.49	44.28	37.09	17.64	43.77	30.98
5	30.98	48.74	38.22	18.9	41.39	30.83
5.1	35.87	46.66	40.57	15.63	41.27	30.57
5.2	32.89	53.36	40.73	16.13	31.85	30.04
5.3	27.61	52.61	41.64	17.09	29.95	30.04
5.4	26.3	50.95	41.23	15.91	31.18	29.93
5.5	29.63	51.94	40.31	14.29	32.45	30.11
5.6	29.09	54.35	39.66	13.1	26.05	29.96
5.7	31.79	57.09	39.55	16.1	26.06	29.39
5.8	31.32	53.03	39.58	16.13	34.96	28.71
5.9	35.84	57.18	39.3	19.52	28.11	27.45
6	36.09	61.91	39.63	20.6	25.48	26.86
6.1	36.8	62.8	38.75	21.52	25.98	26.77
6.2	40.25	54.61	38.69	25.28	22.42	27.75
6.3	33.7	46.14	38.58	27.84	26.88	26.6
6.4	28.51	53.57	36.47	28.66	32.37	23.65
6.5	37.29	54.3	37.23	27.61	31.34	23.95
6.6	38.74	59.41	45.56	26.03	23.84	28.47
6.7	31.43	61.4	47.18	23.23	25.43	29.08
6.8	35.38	62.43	43.81	24.93	18.07	28.66

Appendix D DRILL RESISTANCE ON UNTREATED BOULDER PIT SURFACE

Depth [mm]	Force [N]					
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5	Bore 6
6.9		63.01	40.6	30.37	24.06	29.25
7		61.12	39.29	32.45	29.59	31.22
7.1		61.31	40.31	31.88	35.09	33.59
7.2		60.27	42.37	33.85	39.95	33.51
7.3		60.44	41.52	37	42.15	33.49
7.4		59.85	39.64	37.89	37.19	33.22
7.5		58.8	41.58	35.33	28.2	33.18
7.6		57.39	40.91	27.67	29.14	33.21
7.7		57.53	37.42	32.67	35.91	33.55
7.8		57.56	38.21	35.9	37.84	33.63
7.9		58.17	41.17	34.95	36.53	33.23
8		57.92	41.26	32.82	38.45	33.34
8.1		58.12	37.71	33.16	41.62	33.85
8.2		59.87	38.49	36.47	42.3	31.67
8.3		62.34	37.92	31.91	42.91	30.8
8.4		62.38	39.12	25.6	43.42	31
8.5		62.72	36.33	31.01	44.25	31.59
8.6		62.53	37.3	34.48	45.43	32.78
8.7		61.56	38.45	37.06	44.39	34.28
8.8		61.68	38.3	40.5	45.23	33.67
8.9		60.82	38.97	40.94	46.5	34.17
9		60.78	38.67	40.61	42.9	34.96
9.1		60.85	39.95	40.19	39.47	35.43
9.2		60.49	40.05	39.25	40.88	37.74
9.3		59.3	40.27	37.72	40.03	38.79

Appendix D DRILL RESISTANCE ON UNTREATED BOULDER PIT SURFACE

Depth [mm]	Force [N]					
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5	Bore 6
9.4		60.07	39.57	35.01	38.89	30.13
9.5		59.93	38.99	32.47	37.46	29.87
9.6		59.81	38.61	33.89	40.41	30.92
9.7		60.47		36	42.84	32.53
9.8		60.99		40.61	43.73	32.9
9.9		60.94		43.35	41.08	33.18
10		60.74		43.47	40.23	33.18
10.1		60.33		42.7	43.3	33.02
10.2		59.68		41.46	46.46	32.9
10.3		59.79		40.77	46.08	33.44
10.4		59.87		40.05	48.67	33.15
10.5		58.95		40.32	50.5	33.77
10.6		58.71		39.74	50.77	33.06
10.7		58.03		39.3	53.79	33.27
10.8		58.68		39.93	52.76	33.83
10.9		58.64		39.35	55.68	33.13
11		60.19		39.11	55.29	32.68
11.1		59.75		38.97	55.47	32.53
11.2		60.6		39.15	55.08	33.33
11.3		64.32		38.85	54.5	33.36
11.4		63.92		39.24	54	32.89
11.5		60.24		38.87	53.27	32.97
11.6		57.55		38.74	54.08	33
11.7		57.24		38.74	53.98	32.69
11.8		56.6		38.76	53.77	32.42

Appendix D DRILL RESISTANCE ON UNTREATED BOULDER PIT SURFACE

Depth [mm]	Force [N]					
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5	Bore 6
11.9		59.31		38.03	52.84	32.55
12		55.33		38.61		32.8
12.1		55.13		38.8		32.82
12.2		58.31		38.69		33.05
12.3		58.96		39.03		32.76
12.4		59.74		38.75		32.07
12.5		62.15		38.4		31.89
12.6		69.35		38.47		32.06
12.7		68.16		38.74		30.49
12.8		65.48		38.31		30.07
12.9		64.55		37.83		29.45
13		65.44				28.34
13.1		67.06				27.08
13.2		66.52				27.58
13.3		68.42				29.05
13.4		67.99				29.13
13.5		69.45				29.61
13.6		70.16				29.31
13.7		69.37				28.69
13.8		69.08				28.47
13.9		68.53				28.77
14		68.5				28.88
14.1		68.74				28.93
14.2		68.5				28.1

Appendix D DRILL RESISTANCE ON UNTREATED BOULDER PIT SURFACE

	Force [N]					
Depth [mm]	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5	Bore 6
14.3		68.44				28.77
14.4		68.17				28.99
14.5		68.53				28.58
14.6		67.89				28.89
14.7		67.58				29.01
14.8		67.31				29.05
14.9		67.53				29.06
15		66.87				28.99
15.1		66.92				28.83
15.2		66.3				28.9
15.3		66.54				28.72
15.4		66.26				28.82
15.5		66.64				29.18
15.6		66.33				29.23
15.7		66.16				29.7
15.8		66.33				29.35
15.9		66.26				28.87
16		66.2				28.75
16.1		66.04				28.43
16.2		66.18				28.91
16.3		65.72				28.7
16.4		65.57				28.94
16.5		65.32				28.83
16.6		64.96				28.82

Appendix D DRILL RESISTANCE ON UNTREATED BOULDER PIT SURFACE

Depth [mm]	Force [N]					
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5	Bore 6
16.7		64.84				28.2
16.8		64.77				27.45
16.9		64.37				27.02
17		64.42				28.02
17.1		64.41				27.88
17.2		64.46				28.55
17.3		63.3				28.53
17.4		63.04				28.76
17.5		62.94				29.32
17.6		62.46				28.64
17.7		62.46				28.81
17.8		62.24				28.66
17.9		62.43				29.38
18		62.21				29.25
18.1		61.7				28.86
18.2		61.33				28.83
18.3		62.42				28.53
18.4		61.84				27.8
18.5		61.57				28.23
18.6		61.48				28.24
18.7		61.61				28.1
18.8		60.85				27.97
18.9		60.27				28.42
19		60.85				28.38

Appendix D DRILL RESISTANCE ON UNTREATED BOULDER PIT SURFACE

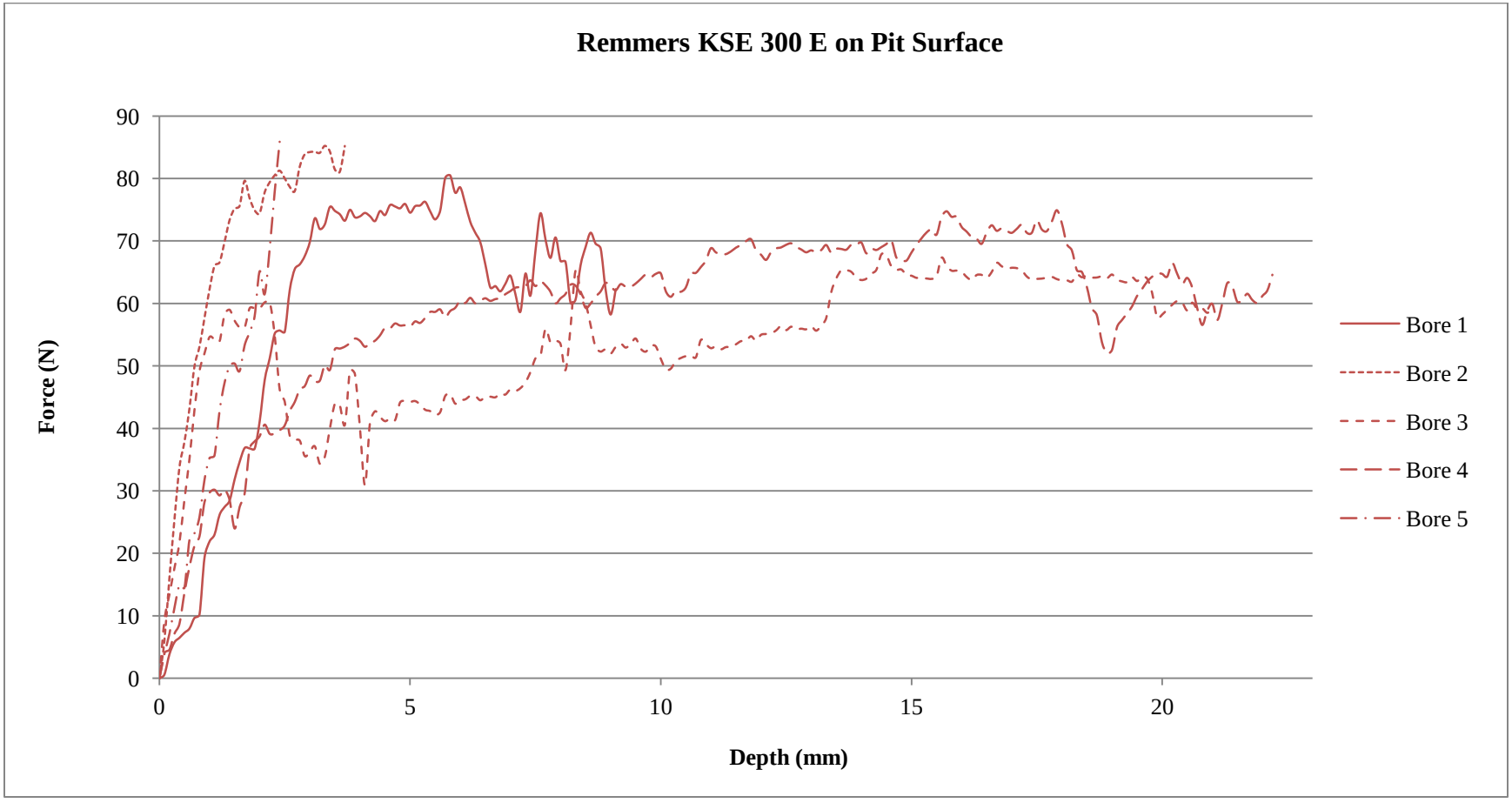
Depth [mm]	Force [N]					
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5	Bore 6
19.1		60.74				27.9
19.2		60.35				27.58
19.3		60.19				28.37
19.4		59.76				27.98
19.5		60.07				27.4
19.6						27.27
19.7						27.51
19.8						27.17
19.9						25.51
20						24.3
20.1						23.96
20.2						24.47
20.3						24.99
20.4						25.64
20.5						25.62
20.6						25.63
20.7						26.68
20.8						26.45
20.9						25.95
21						26.24
21.1						26.54
21.2						27.42
21.3						27.05
21.4						27.24

Appendix D DRILL RESISTANCE ON UNTREATED BOULDER PIT SURFACE

Depth [mm]	Force [N]					
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5	Bore 6
21.5						27.73
21.6						27.72
21.7						26.94
21.8						27.47
21.9						27.4
22						27.19
22.1						27.21
22.2						27
22.3						27.98
22.4						27.05
22.5						27.29
22.6						27.74
22.7						27.09

Appendix D DRILL RESISTANCE ON REMMERS KSE 300 E TREATED PIT SURFACE

3mm carbide tipped bit
600 rpm
10 mm/min



Appendix D DRILL RESISTANCE ON REMMERS KSE 300 E TREATED PIT SURFACE

Depth [mm]	Force [N]				
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5
0	0	0	0	0	0
0.1	0.58	6.04	9.23	4.01	3.83
0.2	3.83	16.07	13.41	4.56	7.12
0.3	5.74	25.38	17.64	7.13	11.26
0.4	6.47	33.77	21.71	8.71	14.94
0.5	7.28	37.85	28.67	13.72	14.49
0.6	7.96	43.19	35.13	17.85	22.16
0.7	9.67	49.94	43.01	21.21	23.21
0.8	10.21	53.09	49.18	22.73	25.82
0.9	19.31	57.69	52.03	28.21	31.77
1	21.88	62.25	54.63	29.71	35.25
1.1	23	66.03	54.25	30.18	35.68
1.2	26.15	66.57	53.95	29.27	42.77
1.3	27.41	69.84	58.26	30.16	47.29
1.4	28.43	73.34	59	28.53	49.96
1.5	31.81	75.17	57.25	23.97	50.39
1.6	34.63	75.6	56.19	27.42	49.17
1.7	36.84	79.64	56.19	29.58	53.28
1.8	36.78	76.84	59.25	36.8	55.38
1.9	36.75	74.93	59.24	37.92	57.93
2	41.14	74.43	59.25	38.75	65.15
2.1	47.72	77.78	60.18	40.6	61.48
2.2	51.2	79.39	60.23	39.13	68.72
2.3	55.16	80.51	54.86	39.19	77.83

Appendix D DRILL RESISTANCE ON REMMERS KSE 300 E TREATED PIT SURFACE

Depth [mm]	Force [N]				
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5
2.4	55.66	81.26	46.17	39.72	85.9
2.5	55.45	80.04	44.27	40.48	
2.6	62.14	78.68	38.83	42.79	
2.7	65.49	77.97	38.19	44.24	
2.8	66.24	81.88	38.04	46.24	
2.9	67.59	83.87	35.57	46.78	
3	69.81	84.23	36.27	48.46	
3.1	73.61	84.28	37.13	47.54	
3.2	71.89	84.11	34.33	47.64	
3.3	72.65	85.23	35.48	50.13	
3.4	75.42	84.37	39.95	49.36	
3.5	74.79	81.47	43.94	52.69	
3.6	74.24	81.08	43.6	52.78	
3.7	73.23	85.21	40.59	53.1	
3.8	74.97		49.26	53.67	
3.9	73.77		48.69	54.39	
4	73.92		40.08	54.02	
4.1	74.47		30.91	53.07	
4.2	73.94		40.93	53.67	
4.3	73.16		42.74	54.04	
4.4	74.77		41.84	54.89	
4.5	74.13		41.16	56.09	
4.6	75.73		41.55	56.03	
4.7	75.5		41.31	56.8	

Appendix D DRILL RESISTANCE ON REMMERS KSE 300 E TREATED PIT SURFACE

Depth [mm]	Force [N]				
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5
4.8	75.21		44.14	56.47	
4.9	75.91		44.42	56.51	
5	74.51		44.25	56.29	
5.1	75.55		44.38	57.13	
5.2	75.66		43.84	56.89	
5.3	76.25		42.99	57.68	
5.4	74.73		42.77	58.65	
5.5	73.43		42.18	58.65	
5.6	74.82		42.59	59.06	
5.7	80.07		45.19	57.8	
5.8	80.47		45.5	58.8	
5.9	77.7		43.97	59.3	
6	78.56		44.52	60.45	
6.1	75.93		44.65	60.08	
6.2	73.03		45.2	60.91	
6.3	71.3		45.19	60.03	
6.4	69.77		44.51	60.43	
6.5	66.24		45.05	60.84	
6.6	62.53		45.08	60.42	
6.7	62.76		44.98	60.7	
6.8	61.92		45.59	60.86	
6.9	63.12		45.42	61.49	
7	64.43		46.23	61.98	
7.1	61.49		45.99	62.53	

Appendix D DRILL RESISTANCE ON REMMERS KSE 300 E TREATED PIT SURFACE

Depth [mm]	Force [N]				
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5
7.2	58.66		46.44	62.63	
7.3	64.76		47.35	62.75	
7.4	61.24		49.01	63.72	
7.5	68.41		51.21	62.79	
7.6	74.42		51.65	63.55	
7.7	70.24		55.91	62.91	
7.8	67.27		53.82	61.88	
7.9	70.55		54.05	60.04	
8	66.77		53.54	60.82	
8.1	66.63		49.34	61.52	
8.2	60.1		56.14	63	
8.3	60.61		65.27	62.86	
8.4	66.1		61.98	61.48	
8.5	69.01		60.09	59.31	
8.6	71.3		56.54	59.98	
8.7	69.53		52.98	61.1	
8.8	68.78		52.3	61.92	
8.9	62.15		52.66	63.3	
9	58.21		51.98	62.75	
9.1	62.26		53.03	62.11	
9.2			53.58	63.1	
9.3			52.94	62.71	
9.4			53.52	62.68	
9.5			54.39	63.2	

Appendix D DRILL RESISTANCE ON REMMERS KSE 300 E TREATED PIT SURFACE

Depth [mm]	Force [N]				
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5
9.6			52.77	63.92	
9.7			52.29	64.61	
9.8			53.17	64.23	
9.9			53.14	64.74	
10			51.16	64.83	
10.1			49.46	61.97	
10.2			49.57	61.07	
10.3			50.8	62.03	
10.4			51.27	61.88	
10.5			51.57	62.57	
10.6			51.69	64.77	
10.7			51.38	64.9	
10.8			54.16	65.84	
10.9			53.47	66.86	
11			52.85	68.85	
11.1			53.12	68.18	
11.2			52.67	67.9	
11.3			53.02	67.91	
11.4			53.02	68.34	
11.5			53.47	68.94	
11.6			53.97	69.38	
11.7			54.01	69.98	
11.8			54.76	70.3	
11.9			54.07	68.56	

Appendix D DRILL RESISTANCE ON REMMERS KSE 300 E TREATED PIT SURFACE

Depth [mm]	Force [N]				
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5
12			54.99	67.81	
12.1			55.12	66.98	
12.2			55.21	68.2	
12.3			55.69	68.81	
12.4			56.38	68.98	
12.5			55.74	69.4	
12.6			56.28	69.64	
12.7			55.85	69.08	
12.8			55.97	68.66	
12.9			55.87	68.2	
13			56.35	68.51	
13.1			55.65	68.2	
13.2			56.46	68.55	
13.3			57.67	69.37	
13.4			61.81	68.14	
13.5			64	68.76	
13.6			65.31	68.73	
13.7			65.35	68.61	
13.8			65.07	69.39	
13.9			64.13	69.37	
14			63.76	69.77	
14.1			63.97	68.04	
14.2			64.77	68.76	
14.3			65.39	68.57	

Appendix D DRILL RESISTANCE ON REMMERS KSE 300 E TREATED PIT SURFACE

Depth [mm]	Force [N]				
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5
14.4			67.87	69.03	
14.5			67.71	69.52	
14.6			65.94	70.1	
14.7			65.4	67.35	
14.8			65.44	67	
14.9			64.59	66.86	
15			64.45	68.15	
15.1			64.11	69.37	
15.2			64.08	70.42	
15.3			64.01	71.36	
15.4			63.94	71.87	
15.5			64.31	71.01	
15.6			67.34	73.83	
15.7			66.05	74.77	
15.8			65.26	73.89	
15.9			65.27	73.89	
16			65.09	72.28	
16.1			64.26	71.52	
16.2			63.77	70.65	
16.3			64.56	70.38	
16.4			64.58	69.55	
16.5			64.1	71.33	
16.6			65.03	72.53	
16.7			66.51	71.64	

Appendix D DRILL RESISTANCE ON REMMERS KSE 300 E TREATED PIT SURFACE

Depth [mm]	Force [N]				
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5
16.8			65.96	72.03	
16.9			65.58	71.63	
17			65.72	71.31	
17.1			65.66	71.94	
17.2			65.3	72.61	
17.3			64.33	71.34	
17.4			63.83	71.31	
17.5			63.94	73.31	
17.6			63.99	71.87	
17.7			64.14	71.58	
17.8			64.26	73.11	
17.9			63.91	74.94	
18			63.7	72.86	
18.1			63.71	69.52	
18.2			63.5	68.5	
18.3			64.62	65.33	
18.4			64.21	65.04	
18.5			64.45	62.63	
18.6			64.17	59.26	
18.7			64.17	58.08	
18.8			64.35	53.8	
18.9			64.05	52.04	
19			64.64	52.56	
19.1			63.82	56.21	

Appendix D DRILL RESISTANCE ON REMMERS KSE 300 E TREATED PIT SURFACE

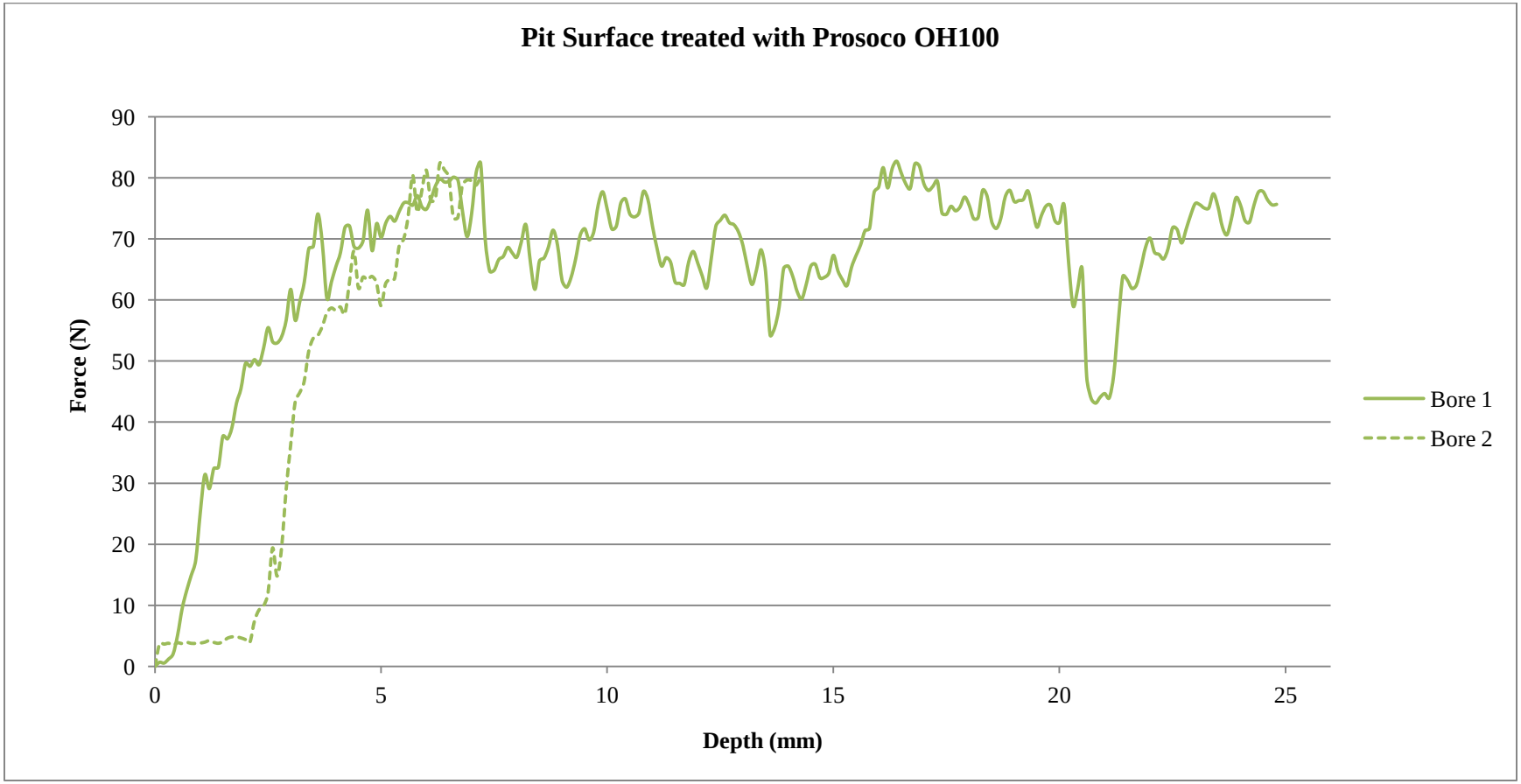
Depth [mm]	Force [N]				
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5
19.2			63.54	57.36	
19.3			63.42	58.41	
19.4			64.2	59.53	
19.5			63.6	61.2	
19.6			64.24	62.32	
19.7			63.98	63.49	
19.8			61.7	64.28	
19.9			57.73	64.8	
20			58.22	64.74	
20.1			59.03	64.29	
20.2			59.79	66.48	
20.3			60.39	64.77	
20.4			60.16	63.15	
20.5			58.89	64.1	
20.6			60.13	62.57	
20.7			59.13	59.27	
20.8			59.23	56.56	
20.9			58.51	58.83	
21			59.1	59.95	
21.1				57.36	
21.2				60.02	
21.3				63.27	
21.4				62.73	
21.5				60.28	

Appendix D DRILL RESISTANCE ON REMMERS KSE 300 E TREATED PIT SURFACE

Depth [mm]	Force [N]				
	Bore 1	Bore 2	Bore 3	Bore 4	Bore 5
21.6				60.61	
21.7				61.56	
21.8				60.56	
21.9				60.09	
22				61.21	
22.1				62.11	
22.2				64.61	

Appendix D DRILL RESISTANCE ON PROSOCO OH100 TREATED PIT SURFACE

3mm carbide tipped bit
600 rpm
10 mm/min



Appendix D DRILL RESISTANCE ON PROSOCO OH100 TREATED PIT SURFACE

Depth [mm]	Force [N]	
	Bore 1	Bore 2
0	0	0
0.1	0.68	3.72
0.2	0.55	3.65
0.3	1.21	3.79
0.4	2.04	3.49
0.5	5.17	3.87
0.6	9.48	3.75
0.7	12.44	3.94
0.8	14.91	3.78
0.9	17.41	3.77
1	25.16	3.83
1.1	31.38	3.97
1.2	29.12	4.23
1.3	32.42	3.94
1.4	32.63	3.79
1.5	37.7	4.04
1.6	37.26	4.61
1.7	39.09	4.84
1.8	43.08	4.84
1.9	45.49	4.67
2	49.61	4.4
2.1	49.14	3.99
2.2	50.25	7.45
2.3	49.42	9.24

Depth [mm]	Force [N]	
	Bore 1	Bore 2
2.4	52.12	9.89
2.5	55.49	12
2.6	53.18	19.39
2.7	52.97	14.79
2.8	54.02	19.46
2.9	56.7	28.9
3	61.76	36.18
3.1	56.67	43.29
3.2	59.73	44.81
3.3	62.92	46.66
3.4	68.41	51.61
3.5	68.81	53.72
3.6	74.11	54.18
3.7	69.2	55.66
3.8	60.29	57.86
3.9	62.96	58.69
4	65.51	58.32
4.1	67.76	58.87
4.2	71.9	57.75
4.3	72.13	62.81
4.4	68.76	68
4.5	68.51	61.98
4.6	69.71	63.74
4.7	74.72	63.29

Appendix D DRILL RESISTANCE ON PROSOCO OH100 TREATED PIT SURFACE

Depth [mm]	Force [N]	
	Bore 1	Bore 2
4.8	68.09	63.86
4.9	72.53	62.82
5	70.26	59.05
5.1	72.58	62.63
5.2	73.7	63.41
5.3	72.92	63.51
5.4	74.54	68.8
5.5	75.9	69.96
5.6	75.94	73.67
5.7	75.54	80.43
5.8	77.1	74.41
5.9	75.29	77.76
6	74.88	81.27
6.1	76.52	76.3
6.2	78.68	76.5
6.3	79.84	82.37
6.4	79.33	81.32
6.5	79.44	80.07
6.6	80.13	73.5
6.7	79.59	73.51
6.8	74.46	78.77
6.9	70.39	79.63
7	74.13	79.52
7.1	80.87	78.79
7.2	82.39	80.06

Depth [mm]	Force [N]	
	Bore 1	Bore 2
7.3	69.98	
7.4	64.74	
7.5	64.89	
7.6	66.62	
7.7	67.14	
7.8	68.62	
7.9	67.71	
8	67.03	
8.1	69.54	
8.2	72.35	
8.3	66.17	
8.4	61.75	
8.5	66.38	
8.6	66.87	
8.7	68.71	
8.8	71.45	
8.9	68.98	
9	63.23	
9.1	62.1	
9.2	63.73	
9.3	66.73	
9.4	70.6	
9.5	71.69	
9.6	69.84	
9.7	71.14	

Appendix D DRILL RESISTANCE ON PROSOCO OH100 TREATED PIT SURFACE

Depth [mm]	Force [N]	
	Bore 1	Bore 2
9.8	75.6	
9.9	77.73	
10	74.82	
10.1	71.65	
10.2	72.12	
10.3	75.9	
10.4	76.58	
10.5	74.08	
10.6	73.62	
10.7	74.26	
10.8	77.81	
10.9	76.42	
11	72.07	
11.1	68.46	
11.2	65.57	
11.3	66.93	
11.4	66.19	
11.5	62.93	
11.6	62.75	
11.7	62.52	
11.8	66.25	
11.9	67.95	
12	66.06	
12.1	63.94	
12.2	62	

Depth [mm]	Force [N]	
	Bore 1	Bore 2
12.3	66.84	
12.4	72.09	
12.5	73.07	
12.6	73.9	
12.7	72.66	
12.8	72.34	
12.9	71.17	
13	68.92	
13.1	65.36	
13.2	62.55	
13.3	64.97	
13.4	68.24	
13.5	64.66	
13.6	54.29	
13.7	55.44	
13.8	58.84	
13.9	65.18	
14	65.56	
14.1	63.9	
14.2	61.36	
14.3	60.2	
14.4	62.61	
14.5	65.56	
14.6	65.86	
14.7	63.66	

Appendix D DRILL RESISTANCE ON PROSOCO OH100 TREATED PIT SURFACE

Depth [mm]	Force [N]	
	Bore 1	Bore 2
14.8	63.72	
14.9	64.43	
15	67.33	
15.1	64.77	
15.2	63.34	
15.3	62.37	
15.4	65.35	
15.5	67.29	
15.6	69.01	
15.7	71.38	
15.8	71.77	
15.9	77.63	
16	78.49	
16.1	81.69	
16.2	78.36	
16.3	81.55	
16.4	82.73	
16.5	80.82	
16.6	79.03	
16.7	78.31	
16.8	82.28	
16.9	81.96	
17	79.06	
17.1	77.95	
17.2	78.62	

Depth [mm]	Force [N]	
	Bore 1	Bore 2
17.3	79.45	
17.4	74.27	
17.5	74.05	
17.6	75.35	
17.7	74.62	
17.8	75.24	
17.9	76.87	
18	75.56	
18.1	73.33	
18.2	73.52	
18.3	77.98	
18.4	76.98	
18.5	72.84	
18.6	71.72	
18.7	73.35	
18.8	76.92	
18.9	77.98	
19	76.13	
19.1	76.3	
19.2	76.47	
19.3	77.88	
19.4	74.9	
19.5	71.93	
19.6	73.87	
19.7	75.39	

Appendix D DRILL RESISTANCE ON PROSOCO OH100 TREATED PIT SURFACE

Depth [mm]	Force [N]	
	Bore 1	Bore 2
19.8	75.52	
19.9	72.96	
20	72.72	
20.1	75.62	
20.2	66.21	
20.3	59.04	
20.4	61.79	
20.5	65.08	
20.6	47.47	
20.7	43.87	
20.8	43.12	
20.9	44.1	
21	44.69	
21.1	43.99	
21.2	47.88	
21.3	56.49	
21.4	63.9	
21.5	63.27	
21.6	61.9	
21.7	62.46	
21.8	65.35	
21.9	68.59	
22	70.15	
22.1	67.81	
22.2	67.48	
22.3	66.73	

Depth [mm]	Force [N]	
	Bore 1	Bore 2
22.4	68.43	
22.5	71.83	
22.6	71.55	
22.7	69.35	
22.8	71.62	
22.9	73.93	
23	75.79	
23.1	75.63	
23.2	75.07	
23.3	75.07	
23.4	77.41	
23.5	75.39	
23.6	72	
23.7	70.68	
23.8	73.26	
23.9	76.74	
24	75.57	
24.1	73.04	
24.2	72.77	
24.3	75.55	
24.4	77.7	
24.5	77.77	
24.6	76.41	
24.7	75.59	
24.8	75.68	

Appendix E LABORATORY INSTRUCTIONS FOR WATER ABSORPTION AND DRYING BEHAVIOR TESTS

HSPV-656 Advanced Architectural Conservation

Laboratory Notes **Prof. A. Elena Charola**

Water Absorption and Drying Behavior

Objective: Determination of:

- Capillary water absorption curve & capillary water absorption coefficient.
- Water absorption by total immersion & porosity.
- Drying curve, drying rate and critical moisture content.
- Total immersion water absorption curve. Determination of the water capacity of the material.

Outline:

The determination of these parameters should be carried out in preference on regular shaped samples, such as 5·5·5 cm cubes, and in a continuous sequence:

I. The capillary water absorption is determined. Once the sample has reached the asymptotical water absorption value continue with step II.

II. The sample is totally immersed in water left for 24 hours and the total amount of water absorbed determined. The weighing carried out corresponds to the first point (t=0) for step II.

III. The sample is left to dry and the drying curve determined by successive weighings.

Based on: NORMAL 11/85; 7/81 and 29/88. ASTM C67-97 and ASTM C948-94, ARC Laboratory Handbook, ICCROM 1999

Procedure to be followed:

I. Capillary water absorption curve & capillary water absorption coefficient.

1. Measure the weight of the oven-dried (60ºC) sample ($\mathbf{W_{dry}}$)[g].
2. Prepare a plastic container with a tight fitting lid in the following manner(s):
   - Put glass rods in the bottom so that when the sample is resting on them it is stable; or,
   - Cover the bottom with a thin sponge cloth.
3. (a) If glass rods are used, fill the container with deionized water until the water level reaches the bottom of the sample.

   (b) If a sponge cloth is used, pour enough deionized water to saturate it, but not flood it, then put the sample on it. Cover the container as hermetically as possible.

4. **As soon as the sample touches the water, i.e., t=0 , and from this moment track of the time has to be kept.**
5. The sample needs to be weighed at different times as it absorbs water. This has to be adjusted according to the porosity of the sample. As a rule of thumb, readings have to be taken closely together at the beginning, and then spaced out as absorption decreases. In general, a first run with weighings every 5 minutes for the first half hour, then every 15 minutes for the second half hour is appropriate. Then every half hour for the next two hours, and after that every hour until the water absorption stabilizes.
6. To weigh the sample, take it out, pat the bottom of the sample dry with a paper towel and put it on the balance. Take the reading as fast as possible and return the sample to the container, making sure to close it again.
7. After the sample has reached the asymptotical water absorption value, leave the sample 24 hours before taking a last weighing. At least 4 points should be obtained for this straight section of the curve.

Data presentation:

- The data should be presented in a Table with at least six columns indicating: actual time of measurement, cumulative time [seconds], square root of time [$sec^{0.5}$], weight of sample $\mathbf{W_t}$ [g], amount of water absorbed $\mathbf{U_t}$ ($U_t = W_t - W_{dry}$)[g] and amount of water absorbed per unit surface $\mathbf{M_i}$ (g/cm^2).
- The capillary water absorption curve plots $\mathbf{M_i}$ vs. **square root of time.**
- The **Capillary Absorption Coefficient** is the **slope** of the initial straight part of the curve expressed in [$g/cm^2\ sec^{0.5}$]. The correlation factor (=1 for a straight line) has to be calculated as well. It should not be lower than 0.995.
- Give the **Asymptotical Water Absorption** value expressed both per unit area **Ma** [g/cm^2] and as total weight of water absorbed $\mathbf{U_{ta}}$ [g].

II. Water absorption by total immersion and determination of porosity.

1. After the last weighing the sample is immediately totally immersed in deionized water and left immersed for another 24 hours.
2. The sample is taken out of the water, lightly patted dry and weighed.

Data presentation:

- The weight of the sample after 24-h immersion is $\mathbf{W_{max}}$ [g] and from it, the total water content, $\mathbf{U_o}$ ($W_{max} - W_{dry}$) [g] is calculated.
- The **Imbibition Capacity IC** is the ratio $[W_{max} - W_{dry}] / W_{dry}$
- The **% Absorption; % Apparent Porosity** or the **Water Absorption Capacity WAC** is the percetange of the above value, that is $[W_{max} - W_{dry}]\ 100 / W_{dry}$

- The ***% Open Porosity*** is calculated based on the ratio of volume of open pores, $\mathbf{V_{op}}$ [cm^3] to the total volume of the sample, $\mathbf{V_s}$ [cm^3]. The volume of open pores $\mathbf{V_{op}}$ [cm^3] is estimated from the total water content $\mathbf{U_0}$ assuming that the density of water is practically 1 g/cm^3. The volume of the sample, V_s [cm^3] can be calculated from its geometrical shape, i.e., 125 cm^3 for a 5·5·5cm cube.

$$\% \text{ Open Porosity} = (V_{op} \cdot 100 / 125)$$

- Compare the water content $\mathbf{U_0}$ with the one obtained from the capillary absorption curve ($\mathbf{U_{ta}}$). What conclusions can be drawn from it regarding the porosity of the sample?

III. Drying Curve

1. As soon as the sample is taken out of the water to be weighed in the previous step, corresponding to t=0 for the drying curve, it is left to dry on the balance for the first half hour, taking readings every 2 or 3 minutes (depending on how fast the sample dries, the faster it dries the more readings should be taken) during the first 15 minutes and then every five minutes.
2. Once the weight of the sample does not change so fast, it can be put to dry on a rack in a draft free environment and its weight loss measured. As a rule of thumb, after the first half hour, weighing should be made every ten minutes for another hour, and then every fifteen minutes, then half an hour, etc.
3. After the weight has reached an asymptotical value and at least four points are obtained of this part of the curve, the sample is dried again in the oven, and this value is used as the dry weight [$\mathbf{W_d}$] for the calculations. If this value changed from the original one, recalculate the total water content $\mathbf{U_o}$ using this value.

Data presentation:

- The data is presented in a table with at least five columns indicating: actual time of measurement; cumulative time [hours]; weight of sample [W_t], water content $\mathbf{U_t}$ [g]; and, moisture content $\mathbf{\Psi}$ ($\Psi = (U_t/Vol._{sample})$ (g/cm^3).
- The **drying curve** is plotted as ***Ψ vs. time***.
- This graph is used to plot the drying rate curve. For this purpose, the following steps are taken:
  1. It is necessary to determine up to which time point the curve is a straight line. Calculate the slope of this straight line and its correlation factor, which should not be lower than 0.995 for this part of the curve. It if is higher, then one point less should be used. Recalculate as many times as necessary until the slope fits the required correlation factor. This is the **initial drying rate** (g/cm^3h)**.**
  2. The last point of the initial drying rate corresponds to the Critical Moisture Content ($\mathbf{\Psi_c}$) and is expressed in g/cm^3 or kg/cm^3.

3. Repeat this procedure for the flat end of the curve. In this case the correlation factor should not be lower than 0.950. Calculate the slope of the straight part at the end of the curve. This is the **final drying rate**.
4. The points in between are simple calculated as follows: $[(\Psi_c - \Psi_{c+1})/ (t_c - t_{c+1})]$ for time (t_{c+1}), and so forth until the first value of the final drying rate is reached.
5. Construct a table where you use the initial drying rate up to time t_c, then use the above calculated points up to the first point which was used in the calculation of the final drying rate, and use the final drying rate for the rest of the time points. Make sure you change the sign for the drying rate values.

- Plot the drying rate as a function of time (hours) using the "line type" chart in Excel. Note, only drying rate column needs to be highlighted. The abscissa (x axis) is automatically put in by the program. Make sure you eliminate the numbers introduced by Excel for this axis since they only represent the "reading" events.
- Express the Critical Moisture Content also as:
    a. Critical relative moisture content $\mathbf{Y_c} = U_c/U_o$), and,
    b. Critical residual water content $\mathbf{Q_c\%} = U_c \cdot 100/W_d$

IV. Conclusions

As a function of the capillary absorption curve, the total immersion data and the drying curve and drying rate curve, draw some conclusions with regards to the pore size distribution of your sample. Does the sample have more coarse pores than fine ones?

If the sample had been treated with a product, does this affect its capillary absorption or its drying characteristics?

Please indicated what other information could be obtained from this experiment.

04 00 00 Masonry
04 40 00 Stone Assemblies
04 20 00 Unit Masonry

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Conservare® OH100 Consolidation Treatment

penetrating stone & masonry strengthener

Of all materials currently and historically employed in construction, masonry is one of the most durable. What has become apparent in recent years, however, is that masonry materials are not as enduring as once believed.

Placed in contemporary urban environments, these "timeless" materials decay at an alarming rate. Some deterioration may be attributed to the masonry's natural weathering process. The majority of the deterioration, however, is the result of oversights in use and maintenance of the masonry, and of the impact that industrialization has had on our environment, i.e. "acid deposition."

The intent of all conservation treatments is to restore the structural integrity to crumbling, decaying masonry and/or provide a means of controlling future decay. The failure of many conservation treatments lies in their inherent dissimilarity to the masonry for which they are proposed as a preservative. When selecting a conservation treatment, an important consideration is to identify those treatments with physical and chemical characteristics similar to the masonry itself.

Conservare® Consolidation Treatments are based on silicic ethyl esters. Their extremely small molecular structure enables them to penetrate deeply into deteriorated masonry surfaces, collecting at contact points between individual stone grains. An internal catalyst and atmospheric humidity then convert the liquid consolidant into a glass-like silicon dioxide (SiO^2) gel which binds the stone particles together. Exhibiting chemical characteristics and thermal expansion/contraction characteristics which are virtually identical to that of natural stone, the newly deposited SiO^2 cementing matrix replaces the stone's natural cement which has been lost due to weathering influences.

OVERVIEW

Conservare® OH100 is a ready-to-use consolidation treatment that stabilizes masonry by replacing the natural binding materials, lost due to weathering, with silicon dioxide. When properly applied, Conservare® OH100 penetrates deeply, does not form a dense surface crust, and retains the substrate's natural vapor permeability.

In addition to the general consolidation of severely deteriorated masonries, Conservare® OH100 is an effective pretreatment for friable substrates that need to be strengthened before cleaning, patching or coating. Conservare® OH100 may be used on most types of natural stone, concrete, stucco, brick, terra-cotta, etc.

Conservare® OH100 is effective on unpolished marble, travertine and limestone that has been treated with Conservare® HCT (Hydroxylating Conversion Treatment).

SPECIFICATIONS

For all PROSOCO product specifications visit www.prosoco.com and click on "SpecBuilder" or "Solution Finder."

ADVANTAGES

- One component – easy-to-use. Strengthens deteriorated stone.
- Low viscosity allows deep penetration. Will not form hardened surface crust.
- The new binder is mineral – similar to the original stone – no synthetic polymers.
- Rapid tack free drying – no dirt attraction.
- Forms no by-products harmful to the masonry.
- Treated surfaces "breathe" – does not trap moisture.
- New binder is acid resistant – resists acid rain.

TYPICAL TECHNICAL DATA

FORM	Colorless to slight yellow
SPECIFIC GRAVITY	0.997
pH	Not applicable
WT/GAL	8.30 lbs
ACTIVE CONTENT	100%
TOTAL SOLIDS	43% ASTM D 5095
VOC CONTENT	>400 g/L
FLASH POINT	104°F (40°C)
FREEZE POINT	<–22°F (<–30°C)
SHELF LIFE	1 year in tightly sealed, unopened container

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OH100 Consolidation Treatment

Limitations

- Effective consolidation requires thorough laboratory and field pretesting. Contact PROSOCO for information on the recommended test programs.
- Limited shelf life – remains storage stable for approximately 12 months in sealed containers. Treated areas may bond to silicone and polyurethane molds (frequently used for casting replacement stone). Use a release agent to prevent molding compounds from adhering to the treated surface.
- Not suitable for architectural concrete block and some types of marble.
- Not suitable for use on polished marble, travertine, limestone or granite.
- Will not prevent water penetration through structural cracks, defects or open joints.
- Not recommended for below-grade application.
- May not be suitable for sale in states and districts with more restrictive AIM VOC regulations. Available in regulation-exempt small container sizes. Call Customer Care at 800-255-4255 for assistance.

REGULATORY COMPLIANCE

VOC Compliance

Conservare® OH100 Consolidation Treatment is compliant with the following national, state and district AIM VOC regulations

[X] US Environmental Protection Agency

[ ] California Air Resources Board SCM Districts

[ ] South Coast Air Quality Management District

[ ] Maricopa County, AZ

[ ] Northeast Ozone Transport Commission

Manufactured and marketed in compliance with USEPA AIM VOC regulations (40 CFR 59.403). VOC Information

THE IMPORTANCE OF PRETESTING

Since building materials differ in their nature and degree of deterioration, each conservation project poses unique problems and requirements. To gain a full understanding of the ongoing deterioration and determine necessary stabilization/ conservation measures, a number of laboratory and field tests are required.

Laboratory Testing

a. Evaluates the physical and chemical characteristics of the substrate(s) to confirm whether consolidation is possible.

b. Identifies the cause(s) of deterioration and surface preparation procedures necessary for conservation treatment.

c. Determines the most appropriate conservation agent(s) and field application procedures.

For more information on the recommended testing program, read the Conservare® Stone Testing Brochure and contact your PROSOCO representative to arrange a job-site visit.

On-Site Testing

Following lab testing, a test area should be cleaned and allowed to dry. An application of Conservare® OH100 Consolidation Treatment is made following specific recommendations provided by the laboratory analysis. The job site test area should be as large as possible and representative of the condition of the entire project.

The test area is necessary to confirm application procedures under job site conditions and allow calculation of the masonry's consumption rate. The on-site tests also provide a visible sample of the effects of the treatment on actual job surfaces. Additional core samples can be taken from the test area and tested to verify depth of penetration and proper application procedures.

ALWAYS TEST

ALWAYS TEST a small area of each surface to confirm suitability and desired results before starting overall application. Test with the same equipment, recommended surface preparation and application procedures planned for general application.

PREPARATION

Following lab and on-site testing, clean the building with the appropriate Sure Klean® product. In most cases, surface contaminants such as carbon crust, salts, pigeon droppings, mildew and atmospheric stains must be completely removed to assure thorough penetration of Conservare® OH100.♦ In addition, surface sealers and repellents which may have been applied must be thoroughly removed. Contact Customer Care at (800) 255-4255 for additional cleaning recommendations.

♦In cases where even the most sympathetic cleaning program would remove an unacceptable level of surface detail, Conservare® OH100 Consolidation Treatment may be applied to the soiled surface to preconsolidate the stone. If such pre-consolidation is necessary, further evaluation will be required to ensure that no undesirable reactions take place between the consolidation treatment and the surface contaminants which may interfere with further conservation measures, i.e. subsequent cleaning, general consolidation, patching/repair, etc.

Protect people, vehicles, property, metal, glass, foliage, painted surfaces and all non masonry surfaces from contact with product, fumes or wind drift. Protect and/or divert pedestrian and auto traffic.

Ensure fresh air entry and cross ventilation during application and drying. Extinguish all flames, pilot lights and other potential sources of ignition during use and until all vapors are gone. When applying to exteriors of occupied buildings, make sure all windows, exterior intakes and air

OH100 Consolidation Treatment

conditioning vents are covered and air handling equipment is shut down during application and until all vapors have dissipated.

Surface and Air Temperatures

Surface and air temperatures should be between 50–90°F (10–32°C) during application. Relative humidity should be greater than 40%. Excessive surface heating can be prevented by shading with awnings.

Protect surface to be treated from direct sunlight for several hours prior to beginning application. When possible, initiate treatment when surfaces are shaded. Keep surface temperature relatively cool to prevent too rapid evaporation of Conservare® OH100 and to ensure proper penetration. Do not apply during rain, to wet surfaces or when there is a chance of rain. Protect from rain for two days following application.

Equipment

Apply by low-pressure spray, brush or dipping. Larger surfaces should be treated using low-pressure spray equipment, small areas with spray tanks. Mobile objects such as sculptures are best treated indoors by dipping or with the use of compresses. Contact Customer Care at 800-255-4255 or your local sales manager for more information.

Storage and Handling

Store in a cool, dry place away from potential ignition sources. Keep tightly closed when not dispensing. Published shelf life assumes upright storage of factory-sealed containers in a dry place. Maintain temperature of 45–100°F (7–38°C). Do not double stack pallets. Dispose of unused product and container in accordance with local, state and federal regulations.

APPLICATION

Before use, read "Preparation" and "Safety Information."

Dilution

Use in concentrate. Do not dilute or alter. Stir or mix well before use.

Coverage Rates

Coverage rates vary depending on the substrate and degree of deterioration. Laboratory and field testing are necessary to confirm desired results and application procedures.

Application Instructions

Ensure proper penetration and prevent crust formations by applying Conservare® OH100 in repeated applications referred to as "cycles." A cycle consists of three successive saturating applications at 5–15 minute intervals. Typical treatments involve two or three cycles (6–9 separate applications). Allow 20 to 60 minutes between cycles. Laboratory testing will determine the optimum delay between applications and between cycles. Additional material should be applied until excess material remains visible on the surface for 60 minutes following the last application. Once this degree of saturation is achieved over the entire surface, the first treatment is complete. Immediately flush excess surface materials using industrial grade MEK (methyl ethyl ketone) or mineral spirits. If a second treatment is necessary, allow two to three weeks curing time following first treatment.

NOTE: Laboratory testing will determine the absorption profile and conservation capacity of the substrate(s). From this information, the optimal delay between saturating coats, and dwell time between cycles will be prescribed. The work area should be limited to a size that can be treated within the prescribed time periods.

Proper timing of the application process will maximize penetration of the consolidation treatment. Deep penetration is critical to the long-term benefits of any consolidation treatment.

BEST PRACTICES

Since building materials differ in their nature and degree of deterioration, each conservation project poses unique problems and requirements. To gain a full understanding of the ongoing deterioration and determine necessary stabilization/conservation measures, a number of laboratory and field tests are required.

Protect surface to be treated from direct sunlight for several hours prior to beginning application. When possible, initiate treatment when surfaces are shaded. Keep surface temperature relatively cool to prevent too rapid evaporation and to ensure proper penetration.

Ensure proper penetration and prevent crust formations by applying Conservare® OH100 in repeated applications referred to as "cycles." A cycle consists of three successive saturating applications at 5–15 minute intervals.

Additional material should be applied until excess material remains visible on the surface for 60 minutes following the last application. Once this degree of saturation is achieved over the entire surface, the first treatment is complete.

Never go it alone. If you have problems or questions, contact your local PROSOCO distributor or field representative. Or call PROSOCO technical Customer Care, toll-free, at 800-255-4255.

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OH100 Consolidation Treatment

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Cleanup
Clean tools and equipment immediately with mineral spirits, denatured alcohol or an equivalent cleaning solvent. Remove over spray and spills as soon as possible.

Post-Treatment
Areas properly treated with Conservare® OH100 can receive stone repair materials, regrouting materials and PROSOCO's BMC® silicone emulsion paints after the consolidation procedures have been completed. After curing apply the appropriate Sure Klean® Weather Seal water repellent to ensure protection from further water damage.

SAFETY INFORMATION
Conservare® OH100 Consolidation Treatment is a solvent carried product and may cause symptoms typical with organic solvent exposures. This is a combustible material. Use appropriate ventilation, safety equipment and job site controls during application and handling. Read the full label for precautionary instructions before use.

First Aid
Ingestion: If swallowed, call a physician immediately. Do not induce vomiting except at the instruction of a physician. If vomiting occurs, keep head below waist to prevent entry of liquid into lungs.

Eye Contact: Rinse eyes thoroughly for 15 minutes. Get medical assistance.

Skin Contact: Rinse thoroughly. Get medical attention if irritation persists. Launder contaminated clothing before reuse.

Inhalation: Remove to fresh air. Give artificial respiration if not breathing. Get immediate medical attention.

24-Hour Emergency Information:
INFOTRAC at 800-535-5053

WARRANTY
The information and recommendations made are based on our own research and the research of others, and are believed to be accurate. However, no guarantee of their accuracy is made because we cannot cover every possible application of our products, nor anticipate every variation encountered in masonry surfaces, job conditions and methods used. The purchasers shall make their own tests to determine the suitability of such products for a particular purpose.

PROSOCO, Inc. warrants this product to be free from defects. **Where permitted by law, PROSOCO makes no other warranties with respect to this product, express or implied, including without limitation the implied warranties of merchantability or fitness for particular purpose**. The purchaser shall be responsible to make his own tests to determine the suitability of this product for his particular purpose. PROSOCO's liability shall be limited in all events to supplying sufficient product to re-treat the specific areas to which defective product has been applied. Acceptance and use of this product absolves PROSOCO from any other liability, from whatever source, including liability for incidental, consequential or resultant damages whether due to breach of warranty, negligence or strict liability. This warranty may not be modified or extended by representatives of PROSOCO, its distributors or dealers.

CUSTOMER CARE
Factory personnel are available for product, environment and job-safety assistance with no obligation. Call 800-255-4255 and ask for Customer Care - technical support.

Factory-trained representatives are established in principal cities throughout the continental United States. Call Customer Care at 800-255-4255, or visit our web site at www.prosoco.com, to find the name of the Conservare® representative in your area.

MATERIAL SAFETY DATA SHEET
PROSOCO, Inc.

I PRODUCT IDENTIFICATION

MANUFACTURER'S NAME AND ADDRESS: PROSOCO, Inc.
3741 Greenway Circle
Lawrence, Kansas 66046

EMERGENCY TELEPHONE NUMBERS:
8:00 AM - 5:00 PM CST Monday-Friday: 785/865-4200
NON-BUSINESS HOURS (INFOTRAC): 800/535-5053

PRODUCT TRADE NAME: Conservare® OH100 Consolidation Treatment

II HAZARDOUS INGREDIENTS

CHEMICAL NAME	(COMMON NAME)	CAS NO.	NFPA CODE	ACGIH TLV/TWA	OSHA PEL/TWA
Di-n-butyltindilaurate	(-)	77-58-7	1,3,0,-	Not established	Not established
Organic Tin Compound	(-)	-	Unknown	0.1 mg/m^3	0.1 mg/m^3
Ethyl Alcohol	(Ethanol)	64-17-5	3,3,0,-	1000 ppm	1000 ppm
Tetra ethyl silicate	(Ethyl Silicate)	78-10-4	2,2,0,-	10 ppm	100 ppm

* Contains some or all of the listed ingredients.

III PHYSICAL DATA

	BOILING POINT (°F)	VAPOR PRESSURE (mm Hg)	VAPOR DENSITY (Air=1)	EVAPORATION RATE (1=Butyl Acetate)
Di-n-butyltindilaurate	N/A	N/A	N/A	N/A
Organic Tin Compound	>401	0.2 (320°F)	N/A	Very Slow
Ethyl Alcohol	180	33 (68°F)	3.0	1.9
Tetra ethyl silicate	302	1.0 (68°F)	Unknown	Unknown

	SPECIFIC GRAVITY	SOLUBILITY IN WATER	APPEARANCE AND ODOR
Conservare® OH100 Consolidation Treatment	0.997(@ 77°F)	Negligible	Clear liquid, alcohol odor

IV FIRE AND EXPLOSION HAZARD DATA

EMERGENCY OVERVIEW

Conservare® OH100 Consolidation Treatment is a clear liquid with a mild alcohol odor. It is a combustible liquid, remove all potential sources of ignition. Product may irritate skin upon contact and may cause lung damage if inhaled. Wear appropriate respiratory protection.

FLASH POINT (Method): 104°F (40°C) (closed cup)

FLAMMABLE LIMITS: Not determined.

EXTINGUISHING MEDIA: Carbon dioxide, dry chemical, alcohol-resistant foam, sand or water-mist. Do not use direct water stream. Do not use direct water stream. Avoid accumulation of water as product will float.

SPECIAL FIRE FIGHTING PROCEDURES: Do not enter confined fire space without proper protective equipment including a NIOSH/MSHA approved self-contained breathing apparatus. Cool fire exposed containers, surrounding equipment and structures with water.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Vapors are heavier than air and may accumulate in low areas or areas inadequately ventilated. Vapors may also travel along the ground to be ignited at location distant from handling site; flashback of flame to handling site may occur. Never use welding or cutting torch on or near drum (even empty) because product (even just residue) can ignite explosively. As a result of hydrolysis, flammable vapors may accumulate in the container head space.

COMBUSTIBLE! Keep container tightly closed. Isolate from oxidizers, heat, and open flame. Closed containers may explode if exposed to extreme heat. Applying to hot surfaces requires special precautions.

V HEALTH HAZARD DATA

PRIMARY ROUTES OF EXPOSURE: Inhalation, skin, eyes.

CARCINOGEN INFORMATION: Not listed (OSHA, IARC, NTP).

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: This product is damaging to the liver and kidneys, and is also toxic to the lungs. Product also causes acute dermatitis and has a narcotic effect.

EFFECTS OF OVEREXPOSURE: Highly irritating to eyes. Moderately irritating to skin. High concentrations may produce anesthetic or narcotic effect. May cause kidney and liver damage and temporary disorder of sight.

EYE CONTACT: Liquid is highly irritating to the eyes. Vapors are also irritating. Possible moderate corneal injury and temporary disorder of sight.

SKIN CONTACT: Liquid is moderately irritating to the skin. Repeated, prolonged contact can result in defatting to the skin which may lead to dermatitis.

INHALATION: Breathing high vapor concentrations or prolonged breathing of lower concentrations can cause nose and throat irritation and may cause headache, dizziness and loss of consciousness.

INGESTION: Liquid ingestion may result in vomiting; aspiration of liquid into the lungs must be avoided as liquid contact with the lungs can result in chemical pneumonitis and pulmonary edema/hemorrhage.

EMERGENCY AND FIRST AID PROCEDURES:

EYE CONTACT: If in eyes, flush with large amounts of water for 15 minutes, holding eyelids apart to ensure flushing of the entire eye surface. Get medical attention immediately.

SKIN CONTACT: Remove material with a waterless skin cleaner, then wash with plenty of soap and water. Remove contaminated clothing and do not reuse until laundered. If persistent irritation occurs, get medical attention.

INHALATION: Remove victim to fresh air and provide oxygen if breathing is difficult. Give artificial respiration if not breathing. Get immediate medical attention. Designate the product.

INGESTION: DO NOT INDUCE VOMITING! Get immediate medical attention. Designate the product. If vomiting occurs spontaneously, keep victim's head below hips to prevent breathing vomitus into lungs.

VI REACTIVITY DATA

STABILITY: Stable at ambient temperatures and atmospheric pressure

CONDITIONS TO AVOID: None known.

INCOMPATIBILITY (MATERIALS TO AVOID): Oxidizing materials, acids, and alkalis, water

HAZARDOUS COMBUSTION OR DECOMPOSITION PRODUCTS: Carbon monoxide, carbon dioxide, silicon dioxide and traces of incompletely burned hydrocarbons. Ethyl alcohol from hydrolysis.

VII SPILL OR LEAK PROCEDURES

SPILL, LEAK AND WASTE DISPOSAL PROCEDURES: STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED: Eliminate potential sources of ignition. Wear appropriate respirator and other protective clothing. Shut off source of leak only if safe to do so. Dike and contain to prevent migration to sewers, soil and surface and ground water. Remove with explosion-proof equipment. Soak up residue with a noncombustible absorbent such as clay or vermiculite; place in drums for proper disposal.

WASTE DISPOSAL METHODS: Dispose of in a facility approved under RCRA regulations for hazardous waste. Containers must be leak-proof and properly labeled.

VIII SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION: Do not breath mists. Wear a NIOSH approved dust/mist respirator as necessary. If Threshold Limit Value (TLV) of the product or any component is exceeded, a NIOSH/MSHA jointly approved air-supplied respirator is advised in absence of proper environmental control. Engineering or administrative controls should be implemented to reduce exposure.

VENTILATION: Provide sufficient general and/or local exhaust ventilation to maintain exposure below TLV(s). Use explosion-proof ventilation as required to control vapor concentrations below the TLV(s). Ventilation may be required during product drying and curing.

PROTECTIVE CLOTHING: Wear protective clothing as required to prevent skin contact.

PROTECTIVE GLOVES: Wear solvent-resistant gloves, such as butyl rubber.

EYE PROTECTION: Chemical splash goggles in compliance with OSHA regulations are recommended. Do not wear contact lenses because they may contribute to the severity of an eye injury.

OTHER PROTECTIVE EQUIPMENT: Solvent-resistant boots and headgear as required. An eyewash should be easily accessible from the work area. Access to a safety shower is recommended.

IX SPECIAL PRECAUTIONS

WORK PRACTICES: Proper work practices and planning should be utilized to avoid contact with workers, passersby, and non-masonry surfaces. Do not atomize during application. Beware of wind drift. Over-application may contribute to fume problems. Always follow published application rates. See the Product Data sheet and label for specific precautions to be taken during use. **This product is combustible!** Always bond and ground containers during transfer. Eliminate all sources of ignition, even remote sources, as vapors may travel some distance. Smoking, eating and drinking should be prohibited during the use of this product. Wash hands before breaks and at the end of a shift.

This product will continue to evolve vapor during drying and ethyl alcohol during curing. Continue ventilation as needed during curing.

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE: Store away from oxidizing materials, in a cool, dry place with adequate ventilation. Keep away from heat and open flames. Keep container tightly closed when not dispensing product. Wash up with soap and water before eating, drinking, smoking or using toilet facilities. Launder contaminated clothing before reuse.

Containers of this material may be hazardous when emptied, since emptied containers retain product residues (vapor, liquid, and/or solid). All hazard precautions given in the Data sheet must be observed.

Ground equipment to prevent accumulation of static charge. Containers must be bonded and grounded when pouring or transferring materials.

OTHER PRECAUTIONS: Environmental Hazards - Keep out of surface water and watercourses or sewers entering or leading to surface waters.

X REGULATORY INFORMATION

SHIPPING: This product is not regulated when shipped domestic ground in its original, complete packaging. The product is reclassified as a hazardous material for shipping by air, ocean, or in international commerce. Consult with PROSOCO's Regulatory Department for shipping information.

National Motor Freight Classification: NMFC#33980 Class Rate: 55

SARA 313 Reportable:

Chemical name	CAS	Upperbound Concentration % by Weight
None	-	-

XI OTHER

MSDS Status:

Date of Revision: December 20, 2010
For Product Manufactured After: N/A – no formulary change
Changes: N/A. Regulatory Review for Canadian Customer. No formulary change.
Item No: 42015
Approved By: Regulatory Department

DISCLAIMER:

The information contained on the Material Safety Data Sheet has been compiled from data considered accurate. This data is believed to be reliable, but it must be pointed out that values for certain properties are known to vary from source to source. **PROSOCO, Inc. expressly disclaims any warranty express or implied as well as any liability for any injury or loss arising from the use of this information or the materials described.** This data is not to be construed as absolutely complete since additional data may be desirable when particular conditions or circumstances exist. It is the responsibility of the user to determine the best precautions necessary for the safe handling and use of this product for his unique application. This data relates only to the specific material designated and is not to be used in combination with any other material. Many federal and state regulations pertain directly or indirectly to the product's end use and disposal of containers and unused material. It is the purchaser's responsibility to familiarize himself with all applicable regulations.

DATE OF PREPARATION: December 20, 2010

Technical Information Sheet
Article No. 0714

KSE 300 E

Elasticised stone strengthener on a silicic acid ethyl ester base. Gel deposit rate approx. 30%

Range of use

Remmers KSE 300 E is preferably used for friable, medium to coarse-pored sandstone, certain volcanic rock (e.g. tuff) as well as weathered brick. It can also be used for strengthening historical renders and joints. Stone that has pronounced swelling and shrinking properties due to swelling capable clay minerals must be treated first with Funcosil Antihygro (Art. No. 0616) to reduce swelling. The stone should be examined in Remmers' laboratory.

Property profile

Remmers KSE 300 E, an elasticised stone strengthener, was developed in co-operation with Dr. E. Wendler (Munich) and a work group directed by Prof. Dr. J. Grobe (Münster) within the framework of a project called "Protecting Stone Surfaces through the Application of Elastic Silicic Acid Ester" which was sponsored by the German Federal Environment Foundation (Osnabrück).
Remmers KSE 300 E differs from conventional stone strengtheners by a

- moderate E-modulus increase (stress-strain behaviour) while at the same time providing
- sufficient consolidation of the natural stone structure.

Remmers KSE 300 E reacts with the water or humidity stored in the pore system. During this reaction, amorphous and hydrous silicon dioxide linked through soft segments is deposited as a binder. The binder silica gel replaces the original binder lost through weathering.
The speed of the gel deposit reaction is highly dependent on temperature and humidity. Under normal conditions (20 °C, 50% relative humidity), the deposit of binder is concluded after approx. three weeks.
The most important property parameters of Remmers KSE 300 E stone strengthener are listed in the following:

Characteristic data of the product

Characteristic data of the product in the packaged state

Active ingredient content:	approx. 50% by mass
Density at 20 °C:	0.9 g/cm³
Colour:	clear, slightly yellow
Odour:	typical
Catalyst system:	neutral

Characteristic data of the product after application

Deposited quantity of gel:	approx. 300 g/l
By-product caused by the reaction:	ethanol (escapes)

- Gel deposit rate approx. 30 %
- Single component system – reliable and easy to use
- Neutral catalyst
- High penetration depth, possible all the way down to the sound core of the stone material
- No by-products that damage the building
- High weather resistance and UV stability
- Partially strengthened natural stone can be worked over with Remmers Restoration Mortar.

Directions

Preliminary examination, setting up trial areas:
The following characteristic properties of the material should be

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determined (analysis of the state of the building):

1. Moisture content, content of damaging salts, hygroscopic water absorption
2. Absorbency, capillary water absorption
3. Strength profile, depth of weathering, degree of hygroscopic swelling
4. Application rate for each area, penetration depth of the stone strengthener, resulting strength profile
5. Establishment of working operations
6. Set-up of a representative trial area which is necessary to see if there will be changes in colour and the correlation between laboratory results and the quantities and values achieved on the object.
7. Execution of treatment and application rates should be controlled and documented.

Preparing the substrate:
Surfaces to be restored often show reduced absorption capacity due to a crust of soil or different types of "patina". The cleaning measures necessary to restore the original absorption behaviour should be as gentle as possible, e.g. by spraying with cold or warm water or by steam cleaning. In case of stubborn soil, the Rotec Low Pressure Blasting Device should be preferably used or Remmers cleaning products (see the respective Technical Information Sheets).
In many cases the stone is already so friable that cleaning cannot take place without a sensitive loss of substance. To avoid this, prestrengthening with Remmers KSE 300 E or another suitable stone strengthener from the Remmers KSE family can be carried out prior to cleaning. The main strengthening measure is then carried out after the cleaned surface has dried.
In order to achieve complete saturation of the weathered zone of the stone with Remmers KSE 300 E, the surface to be treated must have reached compensation moisture balance, be absorbent and should not have been heated by the sun. When strengthening is carried out, the temperature of the stone strengthener as well as the temperature of the substrate and surrounding air should range between 8 °C and 25 °C. To avoid strong heating, use shading devices. The surfaces should be protected from sun, rain and wind before, during and after strengthening.

Application procedures:
An essential prerequisite for optimal strengthening is that the weathered zone is completely saturated all the way down to the sound core. To achieve this, Remmers KSE 300 E stone strengthener is applied to the building material in a flow coating, dipping and/or compress procedure. When using a flow coating procedure, smaller areas (if necessary, stone by stone) are treated, wet-on-wet, with KSE 300 E until the material is no longer absorbed. The procedure selected for application always depends on the task at hand.
So-called "fast hydrolysis" is not recommended since this represents an uncontrolled influence on the gel formation reaction and therefore the success of the strengthening measure.

Notes

If necessary, treatment can be repeated 2-3 weeks after initial treatment. In this case as well, saturation of the complete weathered zone must be achieved. The application rate of Remmers KSE 300 E should be determined in the laboratory during preliminary examinations and on a trial surface and will depend not only on the absorbency of the substrate but also on the application procedure selected.

Follow up treatment:
To avoid a change in the colour of the surface caused by oversaturation with Remmers KSE 300 E, the stone surface should be washed off with a dry solvent (e.g. Thinner V 101) immediately after saturation has been achieved.

Application of stone substitution compounds, hydrophobizing impregnation agents and coats of paint:
Surfaces that have been strengthened with Remmers KSE 300 E can be worked over – after the deposit of gel has been concluded – with Remmers Restoration Mortar, Funcosil impregnation agents and/or products in the Remmers Silicone Resin Paint System.
After application, the "silicic acid ester" chemical system leads to a temporary water repelling effect which disappears during the course of gel formation. If strengthened surfaces still show an annoying water repelling effect when restoration mortar is subsequently applied, this can be suppressed by wetting the surface with alcohol.

Adjoining surfaces:
Facade elements that should not come in contact with the impregnation agent such as, e.g. windows, varnished surfaces, glass and also plants should be protected by suitable measures (e.g. covered with plastic sheets).

Tools, cleaning

Depending on the task at hand, e.g. low pressure spraying equipment, airless equipment, hand sprayers. Tools and equipment must be clean and dry. After use and before longer pauses, they should be cleaned thoroughly with Thinner V 101. Once the stone strengthener has reacted, it can only be removed mechanically.

Packaging, application rate, shelf-life

Packaging:
5 l, 30 l and 200 l tin containers

Application rate:
The application rate of Remmers KSE 300 E depends to a considerable degree on the type and state of the substrate to be treated as well as the task at hand and the application technique used. The quantity required may vary ac-

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cordingly and can range between 0.1 l/m² to several litres per m².

The rate should be determined in the laboratory during preliminary examination as well as on a trial surface.

Shelf-life:
At least 12 months stored cool but frost-free and dry in closed, original containers. Remmers KSE 300 E reacts with humidity/moisture, so close containers air-tight each time material is removed.

Safety, ecology, disposal

Further information on safety when transporting, storing and handling as well as disposal and ecology is found in the latest Safety Data Sheet.

Personal protective equipment is required for spraying procedures. Use respiratory protection with a combination filter at least A/P2 (made by e.g. Dräger). For suitable protective gloves, see Safety Data Sheet. Wear closed work clothes.

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according to 1907/2006/EC, Article 31

Printing date 07.10.2011 Revision: 28.07.2011

*
1 Identification of substance

· **Product details**

· **Trade name** KSE 300

· **Article number:** 0720
· **Application of the substance / the preparation** Stone strengthener

· **Manufacturer/Supplier:**
Remmers Baustofftechnik GmbH
Postfach 1255
D-49624 Löningen / Germany
Tel.: 05432/83-0
Fax: 05432/3985

· **Informing department:**
Product Safety department: Tel.: +49 (0)5432/83-138/-538
E-Mail: sales@remmers.co.uk

· **Emergency information:**
during working hours:
U.K.: Tel.: +44 (0) 845 373 0103
Far East: Tel.: +65(0) 67410277
Head Office Germany: Tel.: +49 (0)5432 83 185
after working hours: Tel.: +49 (0)171/6428-297

*
2 Hazards identification

· **Hazard designation:**

Xn Harmful

· **Information pertaining to particular dangers for man and environment**
R 10 Flammable.
R 20 Harmful by inhalation.
R 36/37 Irritating to eyes and respiratory system.
· **Classification system**
The classification is in line with current EC lists. It is expanded, however, by information from technical literature and by information furnished by supplier companies.

*
3 Composition/information on ingredients

· **Chemical characterization**
· **Description:** silicic acid ethylic ester

· **Dangerous components:**

CAS: 78-10-4 EINECS: 201-083-8	tetraethyl orthosilicate	Xn, Xi; R 10-20-36/37	60-80%

· **Additional information** For the wording of the listed risk phrases refer to section 16.

4 First aid measures

· **General information**
Immediately remove any clothing soiled by the product.

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Trade name KSE 300

(Contd. of page 1)

In case of irregular breathing or respiratory arrest, provide artificial respiration.
· **After inhalation**
Take affected persons into the open air and position comfortably
Seek medical treatment in case of complaints.
· **After skin contact**
Wash immediately with water and soap and rinse thoroughly.
If skin irritation continues, consult a doctor.
· **After eye contact** Rinse opened eye for several minutes under running water. Then consult doctor.

5 Fire fighting measures

· **Suitable extinguishing agents**
Alcohol-resistant foam
Carbon dioxide
Fire-extinguishing powder
· **For safety reasons unsuitable extinguishing agents** Water with a full water jet.
· **Special hazards caused by the material, its products of combustion or flue gases:**
Formation of toxic gases is possible during heating or in case of fire.
· **Protective equipment:** Wear self-contained breathing apparatus.
· **Additional information** Cool endangered containers with water spray jet.

6 Accidental release measures

· **Person-related safety precautions:**
Wear protective equipment. Keep unprotected persons away.
Ensure adequate ventilation
Keep away from ignition sources
· **Measures for environmental protection:**
Do not allow product to reach sewage system or water bodies.
Do not allow to enter the ground/soil.
Inform responsible authorities in case product reaches bodies of water or sewage system.
Inform responsible authorities if the product penetrates into the ground.
· **Measures for cleaning/collecting:**
Absorb with liquid-binding material (sand, diatomite, acid binders, universal binders, sawdust).
Send for recovery or disposal in suitable containers.
Ensure adequate ventilation.
· **Additional information:** See Section 13 for information on disposal.

7 Handling and storage

· **Handling**
· **Information for safe handling:**
Use only in well ventilated areas.
Avoid the formation of aerosols.
· **Information about protection against explosions and fires:**
Keep ignition sources away - Do not smoke.
Protect against electrostatic charges.
Fumes can combine with air to form an explosive mixture.

· **Storage**
· **Requirements to be met by storerooms and containers:** No special requirements.
· **Information on storage in a common storage facility:** Store away from food.
· **Further information about storage conditions:**
Store cool and dry in tightly closed containers.
Protect from humidity and keep away from water.
Store container in a well ventilated position.

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(Contd. of page 2)

Protect from heat and direct sunlight.
Do not smoke in storage areas. Storage temperature: room temperature.

*
8 Exposure controls and personal protection

· **Additional information about design of technical systems:** No further data; see item 7.

· **Components with limit values that require monitoring at the workplace:**	
77-58-7 dibutyltin dilaurate	
WEL	Short-term value: 0.2 mg/m³ Long-term value: 0.1 mg/m³ as Sn; Sk

· **Additional information:** The lists that were valid during compilation were used as a basis.

· **Personal protective equipment**
· **General protective and hygienic measures**
Keep away from food, beverages and animal feed.
Immediately remove soiled, saturated clothing.
Do not eat, drink or smoke while working.
Use skin protection cream for preventive skin protection.
Wash hands before pauses and after work.
Avoid contact with eyes and skin.
Do not inhale gases / vapours / aerosols.
· **Respiratory equipment:**
Respiratory protection if there is a risk of splashes/mist.
Short term filter device:
Filter ABEK/P2
· **Protection of hands:** Impervious gloves
· **Material of gloves** Butyl rubber, BR
· **Penetration time of glove material**
Break through time: max. 240 min (DIN EN 374).
The exact break trough time has to be found out by the manufacturer of the protective gloves and has to be observed.
· **Eye protection:** Tightly sealed safety glasses.
· **Body protection:** Protective work clothing.

*
9 Physical and chemical properties:

· **General Information**	
Form:	Fluid
Colour:	transparent
Odour:	Weak, characteristic
· **Change in condition**	
Melting point/Melting range:	Not determined
Boiling point/Boiling range:	Not determined
· **Flash point:**	40°C
· **Ignition temperature:**	230°C
· **Self-inflammability:**	Product is not self-igniting.
· **Danger of explosion:**	Product is not explosive. However, formation of dangerous explosive vapour/air mixtures is possible.
· **Explosive Limits:**	
Lower:	1.3 Vol %

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(Contd. of page 3)

Upper:	23.0 Vol %
· **Vapour pressure at 20°C:**	1.7 hPa
· **Density at 20°C**	0.98 g/cm³
· **Solubility in / Miscibility with Water:**	Insoluble
· **Viscosity: kinematic at 20°C:**	12 s (DIN 53211/4)

10 Stability and reactivity

· **Thermal decomposition / conditions to be avoided:**
No decomposition if handled and stored according to specifications.
No decomposition if used according to specifications.
· **Dangerous reactions**
Used empty containers may contain product gases which form explosive mixtures with air
· **Dangerous decomposition products:** None if used properly.

*
11 Toxicological information

· **Acute toxicity:**

· **LD/LC50 values that are relevant for classification:**		
78-10-4 tetraethyl orthosilicate		
Inhalative	LC50/4 h	<20 mg/l (Ratte)

· **Primary irritant effect:**
· **on the skin:** No irritating effect.
· **on the eye:** Irritating effect.
· **Sensitisation:** No sensitising effect known.
· **Additional toxicological information:**
The product shows the following dangers based on the calculation method of the General EC Classification Guidelines for Preparations as issued in the latest version:
Irritant

12 Ecological information:

· **General notes:**
Water hazard class 1 : slightly hazardous to water.
Do not allow product to reach ground water, bodies of water or sewage system.

*
13 Notes on disposal:

· **Product:**
· **Recommendation**
Add water to gelled product remains and allow to react. Solid silica gel can be added to building rubble refuse.

· **European waste catalogue**	
17 01 06	mixtures of, or separate fractions of concrete, bricks, tiles and ceramics containing dangerous substances

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Trade name KSE 300

(Contd. of page 4)

· **Uncleaned packaging:**
· **Recommendation:** Disposal must be made according to official regulations.

*
14 Transport information

· **Land transport ADR/RID and GGVS/GGVE (cross-border/domestic)**

· **ADR/RID-GGVS/E Class:** 3 (F1) Flammable liquids.
· **Kemler Number:** 30
· **UN-Number:** 1292
· **Packaging group:** III
· **Danger sign:** 3
· **Designation of goods:** 1292 TETRAETHYL SILICATE
· **Limited quantities (LQ)** LQ7
· **Tunnel restriction code** D/E

· **Maritime transport IMDG/GGVSea:**

· **IMDG/GGVSea Class:** 3
· **UN Number:** 1292
· **Label** 3
· **Packaging group:** III
· **EMS Number:** F-E,S-D
· **Marine pollutant:** -
· **Correct technical name:** TETRAETHYL SILICATE

· **Air transport ICAO-TI and IATA-DGR:**

· **ICAO/IATA Class:** 3
· **UN/ID Number:** 1292
· **Label** 3
· **Packaging group:** III
· **Correct technical name:** TETRAETHYL SILICATE

*
15 Regulatory information

· **Designation according to EC guidelines:**
The product has been classified and labelled in accordance with EC Guidelines / Ordinance on Hazardous Materials (GefStoffV)

· **Code letter and hazard designation of product:**

Xn Harmful

(Contd. on page 6)

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Trade name KSE 300

(Contd. of page 5)

· **Hazard-determining components of labelling:**
tetraethyl orthosilicate

· **Risk phrases:**
10 Flammable.
20 Harmful by inhalation.
36/37 Irritating to eyes and respiratory system.

· **Safety phrases:**
2 Keep out of the reach of children.
23 Do not breathe fumes/aerosol.
25 Avoid contact with eyes.
26 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
46 If swallowed, seek medical advice immediately and show this container or label.
51 Use only in well-ventilated areas.

· **National regulations**

· **Ordinance on hazardous incidents (StFV):**
Threshold quantity according to the ordinance on incidents should be odserved.

· **Water hazard class:**
Water hazard class 1: slightly hazardous to water.
according to appendix 4 VwVwS

16 Other information:

This data is based on our present state of knowledge. However, it does not constitute a guarantee for any specific product features and does not establish a legally valid contractual relationship.
Delivery specifications are found in the respective Technical Information Sheets.

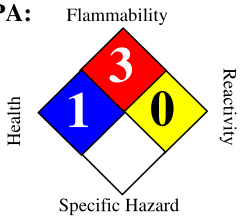
· **Relevant R-phrases**
10 Flammable.
20 Harmful by inhalation.
36/37 Irritating to eyes and respiratory system.

· **Department issuing data specification sheet:** Product Safety department

GB

Material Safety Data Sheet
Naphtha

NFPA:



TESORO

HMIS III:

HEALTH	1
FLAMMABILITY	3
PHYSICAL	0

0 = Insignificant, 1 = Slight, 2 = Moderate, 3 = High, 4 = Extreme

SECTION 1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Naphtha			
Synonyms	:	Light Naphtha, Japan Open Spec Bonded Naphtha, SNG Naphtha, Light Cat Naphtha, Sweet Virgin Naphtha (SVN), Debutanized Naphtha, Atmospheric Naphtha (DAN), HCU Light Naphtha, Light CR Gasoline, Full Range Cracked Naphtha, Full Range Hydrocracked Naphtha, Full Range Reformed Naphtha, Light Chemical Treated Naphtha, Light Cracked Naphtha, Light Hydrocracked Naphtha, Light Hydrotreated Naphtha, Aviation Alkylate Naphtha, 888100004450			
MSDS Number	:	888100004450	**Version**	:	2.12
Product Use Description	:	Fuel Component, Refinery Intermediate Stream			
Company	:	For: Tesoro Refining & Marketing Co. 19100 Ridgewood Parkway, San Antonio, TX 78259			
Tesoro Call Center	:	(877) 783-7676	**Chemtrec (Emergency Contact)**	:	(800) 424-9300

SECTION 2. HAZARDS IDENTIFICATION

Emergency Overview

Regulatory status	:	This material is considered hazardous by the Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (29 CFR 1910.1200).
Signal Word	:	DANGER
Hazard Summary	:	Extremely flammable. Irritating to eyes and respiratory system. Affects central nervous system. Harmful or fatal if swallowed. Aspiration Hazard.

Potential Health Effects

Eyes	:	High vapor concentration or contact may cause irritation and discomfort.
Skin	:	Brief contact may cause slight irritation. Skin irritation leading to dermatitis may occur upon prolonged or repeated contact. Can be absorbed through skin.
Ingestion	:	Aspiration hazard if liquid is inhaled into lungs, particularly from vomiting after ingestion. Aspiration may result in chemical pneumonia, severe lung damage, respiratory failure and even death.
Inhalation	:	Vapors or mists from this material can irritate the nose, throat, and lungs, and can cause signs and symptoms of central nervous system depression, depending on the concentration and duration of exposure. Inhalation of high concentrations may cause central nervous system depression such as dizziness,

drowsiness, headache, and similar narcotic symptoms, but no long-term effects.

Chronic Exposure : Long-term exposure may cause effects to specific organs, such as to the liver, kidneys, blood, nervous system, and skin. Contains benzene, which can cause blood disease, including anemia and leukemia.

Target Organs : Skin, Central nervous system, Liver, Kidney, Blood

SECTION 3. COMPOSITION/INFORMATION ON INGREDIENTS

Component	CAS-No.	Weight %
Naphtha; Low boiling point naphtha	8030-30-6	100%
N-hexane	110-54-3	25 - 35%
Xylene	1330-20-7	25 - 35%
Toluene	108-88-3	15 - 20%
Cyclohexane	110-82-7	15 - 20%
Pentane	109-66-0	15 - 20%
Heptane [and isomers]	142-82-5	12.5 - 15%
Ethylbenzene	100-41-4	5 - 7%
Benzene	71-43-2	3 - 5%
1,2,4-Trimethylbenzene	95-63-6	2 - 3%
Sulfur	7704-34-9	0 - 1.5%

SECTION 4. FIRST AID MEASURES

General advice : Remove from exposure, lie down. In the case of accident or if you feel unwell, seek medical advice immediately (show the label where possible). When symptoms persist or in all cases of doubt, seek medical advice. Never give anything by mouth to an unconscious person. Take off all contaminated clothing immediately and thoroughly wash material from skin.

Inhalation : If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Seek medical attention immediately.

Skin contact : In case of contact, immediately flush skin with plenty of water. Take off contaminated clothing and shoes immediately. Wash contaminated clothing before re-use. Contaminated leather, particularly footwear, must be discarded. Note that contaminated clothing may be a fire hazard. Seek medical advice if symptoms persist or develop.

Eye contact : Remove contact lenses. In the case of contact with eyes, rinse immediately with plenty of water and seek medical advice.

Ingestion : If swallowed Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Seek medical attention immediately.

Notes to physician	:	Symptoms: Dizziness, Discomfort, Headache, Nausea, Kidney disorders, Liver disorders.

SECTION 5. FIRE-FIGHTING MEASURES

Form	:	Liquid
Flash point -typical	:	-21.7 °C (-7.1 °F)
Auto Ignition temperature	:	225 °C (437 °F)
Lower explosive limit	:	1.2 %(V)
Upper explosive limit	:	6.9 % (V)
Suitable extinguishing media	:	Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide. Do not use a solid water stream as it may scatter and spread fire.
Specific hazards during fire fighting	:	SMALL FIRES: Any extinguisher suitable for Class B fires, dry chemical, CO2, water spray, fire fighting foam, or Halon. LARGE FIRES: Water spray, fog or fire fighting foam. Water may be ineffective for fighting the fire, but may be used to cool fire-exposed containers.
Special protective equipment for fire-fighters	:	Fire fighters should wear positive pressure self-contained breathing apparatus (SCBA) and full turnout gear. Firefighters' protective clothing will provide limited protection.
Further information	:	Isolate area around container involved in fire. Cool tanks, shells, and containers exposed to fire and excessive heat with water. For massive fires the use of unmanned hose holders or monitor nozzles may be advantageous to further minimize personnel exposure. Major fires may require withdrawal, allowing the tank to burn. Large storage tank fires typically require specially trained personnel and equipment to extinguish the fire, often including the need for properly applied fire fighting foam. Exposure to decomposition products may be a hazard to health. Use extinguishing measures that are appropriate to local circumstances and the surrounding environment. Use water spray to cool unopened containers. Fire residues and contaminated fire extinguishing water must be disposed of in accordance with local regulations.

SECTION 6. ACCIDENTAL RELEASE MEASURES

Personal precautions	:	Evacuate personnel to safe areas. Ventilate the area. Remove all sources of ignition. Response and clean-up crews must be properly trained and must utilize proper protective equipment (see Section 8).
Environmental precautions	:	Should not be released into the environment. Avoid subsoil penetration. If the product contaminates rivers and lakes or drains, inform respective authorities.
Methods for cleaning up	:	Contain and collect spillage with non-combustible absorbent material, (e.g. sand, earth, diatomaceous earth, vermiculite) and place in container for disposal according to local / national regulations.

SECTION 7. HANDLING AND STORAGE

Handling	:	Keep away from fire, sparks and heated surfaces. No smoking near areas where material is stored or handled. The product should only be stored and handled in

areas with intrinsically safe electrical classification.

Advice on protection against fire and explosion : Hydrocarbon liquids including this product can act as a non-conductive flammable liquid (or static accumulators), and may form ignitable vapor-air mixtures in storage tanks or other containers. Precautions to prevent static-initated fire or explosion during transfer, storage or handling, include but are not limited to these examples:

(1) Ground and bond containers during product transfers. Grounding and bonding may not be adequate protection to prevent ignition or explosion of hydrocarbon liquids and vapors that are static accumulators.

(2) Special slow load procedures for "switch loading" must be followed to avoid the static ignition hazard that can exist when higher flash point material (such as fuel oil or diesel) is loaded into tanks previously containing low flash point products (such gasoline or naphtha).

(3) Storage tank level floats must be effectively bonded.

For more information on precautions to prevent static-initated fire or explosion, see NFPA 77, Recommended Practice on Static Electricity (2007), and API Recommended Practice 2003, Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents (2008).

Dust explosion class : Not applicable

Requirements for storage areas and containers : Keep away from flame, sparks, excessive temperatures and open flame. Use approved containers. Keep containers closed and clearly labeled. Empty or partially full product containers or vessels may contain explosive vapors. Do not pressurize, cut, heat, weld or expose containers to sources of ignition. Store in a well-ventilated area. The storage area should comply with NFPA 30 "Flammable and Combustible Liquid Code". The cleaning of tanks previously containing this product should follow API Recommended Practice (RP) 2013 "Cleaning Mobile Tanks In Flammable and Combustible Liquid Service" and API RP 2015 "Cleaning Petroleum Storage Tanks".

Advice on common storage : Keep away from food, drink and animal feed. Incompatible with oxidizing agents. Incompatible with acids.

Other data : No decomposition if stored and applied as directed.

SECTION 8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Exposure Guidelines

List	Components	CAS-No.	Type:	Value
OSHA	Benzene - 29 CFR 1910.1028	71-43-2	TWA	1 ppm
		71-43-2	STEL	5 ppm
		71-43-2	OSHA_AL	0.5 ppm
OSHA Z1	Naphtha; Low boiling point naphtha	8030-30-6	PEL	100 ppm 400 mg/m3
	Xylene	1330-20-7	PEL	100 ppm 435 mg/m3
	N-hexane	110-54-3	PEL	500 ppm 1,800 mg/m3
	Cyclohexane	110-82-7	PEL	300 ppm 1,050 mg/m3
	Heptane [and isomers]	142-82-5	PEL	500 ppm 2,000 mg/m3
	Ethylbenzene	100-41-4	PEL	100 ppm 435 mg/m3
ACGIH	Naphtha; Low boiling point naphtha	8030-30-6	TWA	400 ppm

	Xylene	1330-20-7	TWA	100 ppm
		1330-20-7	STEL	150 ppm
	N-hexane	110-54-3	TWA	50 ppm
	Toluene	108-88-3	TWA	50 ppm
	Cyclohexane	110-82-7	TWA	100 ppm
	Pentane	109-66-0	TWA	600 ppm
	Heptane [and isomers]	142-82-5	TWA	400 ppm
		142-82-5	STEL	500 ppm
	Ethylbenzene	100-41-4	TWA	100 ppm
		100-41-4	STEL	125 ppm
	Benzene	71-43-2	TWA	0.5 ppm
		71-43-2	STEL	2.5 ppm

Engineering measures : Use adequate ventilation to keep gas and vapor concentrations of this product below occupational exposure and flammability limits, particularly in confined spaces. Use only intrinsically safe electrical equipment approved for use in classified areas.

Eye protection : Safety glasses or goggles are recommended where there is a possibility of splashing or spraying. Ensure that eyewash stations and safety showers are close to the workstation location.

Hand protection : Gloves constructed of nitrile or neoprene are recommended. Consult manufacturer specifications for further information.

Skin and body protection : If needed to prevent skin contact, chemical protective clothing such as of DuPont TyChem®, Saranex or equivalent recommended based on degree of exposure. The resistance of specific material may vary from product to product as well as with degree of exposure.

Respiratory protection : A NIOSH/ MSHA-approved air-purifying respirator with organic vapor cartridges or canister may be permissible under certain circumstances where airborne concentrations are or may be expected to exceed exposure limits or for odor or irritation. Protection provided by air-purifying respirators is limited. Refer to OSHA 29 CFR 1910.134, ANSI Z88.2-1992, NIOSH Respirator Decision Logic, and the manufacturer for additional guidance on respiratory protection selection. Use a NIOSH/ MSHA-approved positive-pressure supplied-air respirator if there is a potential for uncontrolled release, exposure levels are not known, in oxygen-deficient atmospheres, or any other circumstance where an air-purifying respirator may not provide adequate protection.

Work / Hygiene practices : Emergency eye wash capability should be available in the near proximity to operations presenting a potential splash exposure. Use good personal hygiene practices. Avoid repeated and/or prolonged skin exposure. Wash hands before eating, drinking, smoking, or using toilet facilities. Do not use as a cleaning solvent on the skin. Do not use solvents or harsh abrasive skin cleaners for washing this product from exposed skin areas. Waterless hand cleaners are effective. Promptly remove contaminated clothing and launder before reuse. Use care when laundering to prevent the formation of flammable vapors which could ignite via washer or dryer. Consider the need to discard contaminated leather shoes and gloves.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

Form	:	Liquid
Appearance	:	Colorless to light yellow
Odor	:	Characteristic hydrocarbon-like
Flash point - typical	:	-21.7 °C (-7.1 °F)
Auto Ignition temperature	:	225 °C (437 °F)
Thermal decomposition	:	Heating can release hazardous gases, No decomposition if stored and applied as directed.
Lower explosive limit	:	1.2 % (V)
Upper explosive limit	:	6.9 % (V)
pH	:	Not applicable
Specific gravity	:	0.77 (H20=1)
Boiling point	:	26.7 - 148.9 °C(80.1 - 300.0 °F)
Vapor Pressure	:	758 - 896 hPa at 20 °C (68 °F)
Vapor Density (Air = 1)	:	3.5
Water solubility	:	Negligible
Viscosity, kinematic	:	Not determined
Percent Volatiles	:	100 %
Work / Hygiene practices		Emergency eye wash capability should be available in the near proximity to operations presenting a potential splash exposure. Use good personal hygiene practices. Avoid repeated and/or prolonged skin exposure. Wash hands before eating, drinking, smoking, or using toilet facilities. Do not use as a cleaning solvent on the skin. Do not use solvents or harsh abrasive skin cleaners for washing this product from exposed skin areas. Waterless hand cleaners are effective. Promptly remove contaminated clothing and launder before reuse. Use care when laundering to prevent the formation of flammable vapors which could ignite via washer or dryer. Consider the need to discard contaminated leather shoes and gloves.

SECTION 10. STABILITY AND REACTIVITY

Conditions to avoid	:	Avoid high temperatures, open flames, sparks, welding, smoking and other ignition sources.
Materials to avoid	:	Strong acids and strong bases. Oxidizing agents.
Hazardous decomposition products	:	Carbon monoxide, carbon dioxide and noncombusted hydrocarbons (smoke).
Thermal decomposition	:	Heating can release hazardous gases. No decomposition if stored and applied as directed.
Hazardous reactions	:	Vapors may form explosive mixture with air. Hazardous polymerization does not occur. Note: Stable under recommended storage conditions.

SECTION 11. TOXICOLOGICAL INFORMATION

Carcinogenicity

NTP	:	Benzene (CAS-No.: 71-43-2)
IARC	:	Ethylbenzene (CAS-No.: 100-41-4) Benzene (CAS-No.: 71-43-2)
OSHA	:	Benzene (CAS-No.: 71-43-2)
CA Prop 65	:	WARNING! This product contains a chemical known to the State of California to cause cancer. Ethylbenzene (CAS-No.: 100-41-4) Benzene (CAS-No.: 71-43-2)
	:	WARNING! This product contains a chemical known to the State of California to cause birth defects or other reproductive harm. Toluene (CAS-No.: 108-88-3) Benzene (CAS-No.: 71-43-2)
Skin irritation	:	Repeated or prolonged contact with the preparation may cause removal of natural fat from the skin resulting in desiccation of the skin. The product may be absorbed through the skin.
Eye irritation	:	The liquid splashed in the eyes may cause irritation and reversible damage. Strong lachrymation can make it difficult to escape
Further information	:	This product contains benzene. Human health studies indicate that prolonged and/or repeated overexposure to benzene may cause damage to the blood-forming system (particularly bone marrow), and serious blood disorders such as aplastic anemia and leukemia. Benzene is listed as a human carcinogen by the NTP, IARC, OSHA and ACGIH. Acute toxicity of benzene results primarily from depression of the central nervous system (CNS). Inhalation of concentrations over 50 ppm can produce headache, lassitude, weariness, dizziness, drowsiness, or excitation. Exposure to very high levels can result in unconsciousness and death. Symptoms of overexposure may be headache, dizziness, tiredness, nausea and vomiting. Ingestion may cause gastrointestinal disturbances, including irritation, nausea, vomiting and diarrhea, and central nervous (brain) effects similar to alcohol intoxication. In severe cases, tremors, convulsions, loss of consciousness, coma, respiratory arrest and death may occur.

Component:

N-hexane	110-54-3	Acute oral toxicity: LD50 rat Dose: 25,000 mg/kg Acute dermal toxicity: LD50 rabbit Dose: 2,001 mg/kg Acute inhalation toxicity: LC50 rat Dose: 171.6 mg/l Exposure time: 4 h Skin irritation: Classification: Irritating to skin. Result: Skin irritation Eye irritation: Classification: Irritating to eyes. Result: Mild eye irritation Teratogenicity: N11.00418960
Xylene	1330-20-7	Acute oral toxicity: LD50 rat Dose: 2,840 mg/kg Acute dermal toxicity: LD50 rabbit Dose: ca. 4,500 mg/kg Acute inhalation toxicity: LC50 rat Dose: 6,350 mg/l Exposure time: 4 h Skin irritation: Classification: Irritating to skin. Result: Mild skin irritation Repeated or prolonged exposure may cause skin irritation and dermatitis, due to degreasing properties of the product. Eye irritation: Classification: Irritating to eyes. Result: Mild eye irritation
Toluene	108-88-3	Acute oral toxicity: LD50 rat Dose: 636 mg/kg Acute dermal toxicity: LD50 rabbit Dose: 12,124 mg/kg Acute inhalation toxicity: LC50 rat Dose: 49 mg/l Exposure time: 4 h Skin irritation: Classification: Irritating to skin. Result: Mild skin irritation Prolonged skin contact may defat the skin and produce dermatitis. Eye irritation: Classification: Irritating to eyes. Result: Mild eye irritation
Cyclohexane	110-82-7	Acute dermal toxicity: LD50 rabbit Dose: 2,001 mg/kg Acute inhalation toxicity: LC50 rat Dose: 14 mg/l Exposure time: 4 h Skin irritation: Classification: Irritating to skin. Result: Skin irritation Eye irritation: Classification: Irritating to eyes. Result: Mild eye irritation
Pentane	109-66-0	Acute oral toxicity: LD50 rat Dose: 2,001 mg/kg Acute inhalation toxicity: LC50 rat

		Dose: 364 mg/l Exposure time: 4 h Skin irritation: Repeated or prolonged exposure may cause skin irritation and dermatitis, due to degreasing properties of the product. Eye irritation: Classification: Irritating to eyes. Result: Mild eye irritation
Heptane [and isomers]	142-82-5	Acute oral toxicity: LD50 rat Dose: 15,001 mg/kg Acute inhalation toxicity: LC50 rat Dose: 103 g/m3 Exposure time: 4 h Skin irritation: Classification: Irritating to skin. Result: Skin irritation Repeated or prolonged exposure may cause skin irritation and dermatitis, due to degreasing properties of the product. Eye irritation: Classification: Irritating to eyes. Result: Mild eye irritation
Ethylbenzene	100-41-4	Acute oral toxicity: LD50 rat Dose: 3,500 mg/kg Acute dermal toxicity: LD50 rabbit Dose: 15,500 mg/kg Acute inhalation toxicity: LC50 rat Dose: 18 mg/l Exposure time: 4 h Skin irritation: Classification: Irritating to skin. Result: Mild skin irritation Eye irritation: Classification: Irritating to eyes. Result: Risk of serious damage to eyes.
Benzene	71-43-2	Acute oral toxicity: LD50 rat Dose: 930 mg/kg Acute inhalation toxicity: LC50 rat Dose: 44 mg/l Exposure time: 4 h Skin irritation: Classification: Irritating to skin. Result: Mild skin irritation Repeated or prolonged exposure may cause skin irritation and dermatitis, due to degreasing properties of the product. Eye irritation: Classification: Irritating to eyes. Result: Risk of serious damage to eyes.
1,2,4-Trimethylbenzene	95-63-6	Acute inhalation toxicity: LC50 rat Dose: 18 mg/l Exposure time: 4 h Skin irritation: Classification: Irritating to skin. Result: Skin irritation Eye irritation: Classification: Irritating to eyes. Result: Eye irritation

Sulfur	7704-34-9	Acute oral toxicity: LD50 rat Dose: 5,001 mg/kg Acute dermal toxicity: LD50 rabbit Dose: 2,001 mg/kg Acute inhalation toxicity: LC50 rat Dose: 9.24 mg/l Exposure time: 4 h Eye irritation: Classification: Irritating to eyes. Result: Mild eye irritation

SECTION 12. ECOLOGICAL INFORMATION

Additional ecological information : Keep out of sewers, drainage areas, and waterways. Report spills and releases, as applicable, under Federal and State regulations.

Component:

N-hexane	110-54-3	Toxicity to fish: LC50 Species: Pimephales promelas (fathead minnow) Dose: 2.5 mg/l Exposure time: 96 h Acute and prolonged toxicity for aquatic invertebrates: EC50 Species: Daphnia magna (Water flea) Dose: 2.1 mg/l Exposure time: 48 h
Toluene	108-88-3	Toxicity to fish: LC50 Species: Carassius auratus (goldfish) Dose: 13 mg/l Exposure time: 96 h Acute and prolonged toxicity for aquatic invertebrates: EC50 Species: Daphnia magna (Water flea) Dose: 11.5 mg/l Exposure time: 48 h Toxicity to algae: IC50 Species: Selenastrum capricornutum (green algae) Dose: 12 mg/l Exposure time: 72 h
Cyclohexane	110-82-7	Acute and prolonged toxicity for aquatic invertebrates: EC50 Species: Daphnia magna (Water flea) Dose: 3.78 mg/l Exposure time: 48 h
Pentane	109-66-0	Acute and prolonged toxicity for aquatic invertebrates: EC50 Species: Daphnia magna (Water flea) Dose: 9.74 mg/l Exposure time: 48 h
Heptane [and isomers]	142-82-5	Toxicity to fish: LC50 Species: Carassius auratus (goldfish) Dose: 4 mg/l Exposure time: 24 h

		Acute and prolonged toxicity for aquatic invertebrates: EC50 Species: Daphnia magna (Water flea) Dose: 1.5 mg/l Exposure time: 48 h
1,2,4-Trimethylbenzene	95-63-6	Toxicity to fish: LC50 Species: Pimephales promelas (fathead minnow) Dose: 7.72 mg/l Exposure time: 96 h Acute and prolonged toxicity for aquatic invertebrates: EC50 Species: Daphnia Dose: 3.6 mg/l Exposure time: 48 h
Sulfur	7704-34-9	Acute and prolonged toxicity for aquatic invertebrates: EC0 Species: Daphnia magna (Water flea) Dose: > 10,000 mg/l Exposure time: 24 h

SECTION 13. DISPOSAL CONSIDERATIONS

Disposal : Dispose of container and unused contents in accordance with federal, state and local requirements.

SECTION 14. TRANSPORT INFORMATION

CFR

Proper shipping name	: PETROLEUM DISTILLATES, N.O.S.
UN-No.	: 1268
Class	: 3
Packing group	: II
Hazard inducer	: (Naphtha; Low boiling point naphtha)

TDG

Proper shipping name	: PETROLEUM DISTILLATES, N.O.S.
UN-No.	: UN1268
Class	: 3
Packing group	: II
Hazard inducer	: (Naphtha; Low boiling point naphtha)

IATA Cargo Transport

UN UN-No.	: UN1268
Description of the goods	: PETROLEUM DISTILLATES, N.O.S. (Naphtha; Low boiling point naphtha)
Class	: 3
Packaging group	: II
ICAO-Labels	: 3
Packing instruction (cargo aircraft)	: 364
Packing instruction (cargo aircraft)	: Y341

IATA Passenger Transport

UN UN-No.	:	UN1268
Description of the goods	:	PETROLEUM DISTILLATES, N.O.S. (Naphtha; Low boiling point naphtha)
Class	:	3
Packaging group	:	II
ICAO-Labels	:	3
Packing instruction (passenger aircraft)	:	353
Packing instruction (passenger aircraft)	:	Y341

IMDG-Code

UN-No.	:	UN 1268
Description of the goods	:	PETROLEUM DISTILLATES, N.O.S. (Naphtha; Low boiling point naphtha)
Class	:	3
Packaging group	:	II
IMDG-Labels	:	3
EmS Number	:	F-E S-E
Marine pollutant	:	No

SECTION 15. REGULATORY INFORMATION

OSHA Hazards : Flammable liquid
Moderate skin irritant
Severe eye irritant
Carcinogen
Teratogen

TSCA Status : On TSCA Inventory

DSL Status : All components of this product are on the Canadian DSL list.

SARA 311/312 Hazards : Fire Hazard
Acute Health Hazard
Chronic Health Hazard

SARA III US. EPA Emergency Planning and Community Right-To-Know Act (EPCRA) SARA Title III Section 313 Toxic Chemicals (40 CFR 372.65) - Supplier Notification Required

Components	CAS-No.
1,2,4-Trimethylbenzene	95-63-6
Benzene	71-43-2
Ethylbenzene	100-41-4
Cyclohexane	110-82-7
Toluene	108-88-3
N-hexane	110-54-3
Xylene	1330-20-7

PENN RTK US. Pennsylvania Worker and Community Right-to-Know Law (34 Pa. Code Chap. 301-323)

Components	CAS-No.
Heptane [and isomers]	142-82-5
Ethylbenzene	100-41-4
Benzene	71-43-2
1,2,4-Trimethylbenzene	95-63-6
Sulfur	7704-34-9
Pentane	109-66-0
Naphtha; Low boiling point naphtha	8030-30-6
Xylene	1330-20-7
N-hexane	110-54-3
Toluene	108-88-3
Cyclohexane	110-82-7

MASS RTK — US. Massachusetts Commonwealth's Right-to-Know Law (Appendix A to 105 Code of Massachusetts Regulations Section 670.000)

Components	CAS-No.
Heptane [and isomers]	142-82-5
Ethylbenzene	100-41-4
Benzene	71-43-2
1,2,4-Trimethylbenzene	95-63-6
Sulfur	7704-34-9
Naphtha; Low boiling point naphtha	8030-30-6
Xylene	1330-20-7
N-hexane	110-54-3
Toluene	108-88-3
Cyclohexane	110-82-7

NJ RTK — US. New Jersey Worker and Community Right-to-Know Act (New Jersey Statute Annotated Section 34:5A-5)

Components	CAS-No.
Heptane [and isomers]	142-82-5
Ethylbenzene	100-41-4
Benzene	71-43-2
1,2,4-Trimethylbenzene	95-63-6
Sulfur	7704-34-9
Naphtha; Low boiling point naphtha	8030-30-6
Xylene	1330-20-7
N-hexane	110-54-3

Toluene	108-88-3
Cyclohexane	110-82-7

CERCLA SECTION 103 and SARA SECTION 304 (RELEASE TO THE ENVIROMENT)
The CERCLA definition of hazardous substances contains a "petroleum exclusion" clause which exempts crude oil. Fractions of crude oil, and products (both finished and intermediate) from the crude oil refining process and any indigenous components of such from the CERCLA Section 103 reporting requirements. However, other federal reporting requirements, including SARA Section 304, as well as the Clean Water Act may still apply.

California Prop. 65 : WARNING! This product contains a chemical known to the State of California to cause cancer.

Ethylbenzene	100-41-4
Benzene	71-43-2

WARNING! This product contains a chemical known to the State of California to cause birth defects or other reproductive harm.

Toluene	108-88-3
Benzene	71-43-2

SECTION 16. OTHER INFORMATION

Further information

The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text.

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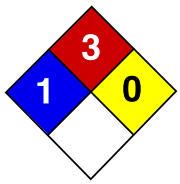
79, 80, 81, 83, 165, 264, 318, 1017, 1018, 1019, 1020, 1021, 1027, 1032, 1055, 1136, 1716



Material Safety Data Sheet
Methyl ethyl ketone MSDS

Section 1: Chemical Product and Company Identification

Product Name: Methyl ethyl ketone

Catalog Codes: SLM2626, SLM3232

CAS#: 78-93-3

RTECS: EL6475000

TSCA: TSCA 8(b) inventory: Methyl ethyl ketone

CI#: Not applicable.

Synonym: 2-Butanone

Chemical Name: Methyl Ethyl Ketone

Chemical Formula: C4H8O

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Methyl ethyl ketone	78-93-3	100

Toxicological Data on Ingredients: Methyl ethyl ketone: ORAL (LD50): Acute: 2737 mg/kg [Rat]. 4050 mg/kg [Mouse]. DERMAL (LD50): Acute: 6480 mg/kg [Rabbit]. VAPOR (LC50): Acute: 23500 mg/m 8 hours [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of skin contact (irritant, permeator), of eye contact (irritant), of ingestion, of inhalation (lung irritant).

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Mutagenic for bacteria and/or yeast. TERATOGENIC EFFECTS: Classified POSSIBLE for human. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to gastrointestinal tract, upper respiratory tract, skin, eyes, central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:

Check for and remove any contact lenses. Immediately flush eyes with running water for at least 15 minutes, keeping eyelids open. Cold water may be used. Get medical attention.

Skin Contact:
In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention if symptoms appear.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Flammable.

Auto-Ignition Temperature: 404°C (759.2°F)

Flash Points: CLOSED CUP: -9°C (15.8°F). OPEN CUP: -5.5556°C (22°F) (Tag).

Flammable Limits: LOWER: 1.8% UPPER: 10%

Products of Combustion: These products are carbon oxides (CO, CO2).

Fire Hazards in Presence of Various Substances: Highly flammable in presence of open flames and sparks, of heat.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available. Explosive in presence of oxidizing materials, of acids.

Fire Fighting Media and Instructions:
Flammable liquid, soluble or dispersed in water. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use alcohol foam, water spray or fog.

Special Remarks on Fire Hazards:
Ignition on contact with potassium t-butoxide. Vapor may cause a flash fire

Special Remarks on Explosion Hazards:
Reaction with Hydrogen Peroxide + nitric acid forms heat and shock-sensitive explosive product. Mixture with 2-propanol will produce explosive peroxides during storage.

Section 6: Accidental Release Measures

Small Spill:
Dilute with water and mop up, or absorb with an inert dry material and place in an appropriate waste disposal container.

Large Spill:
Flammable liquid. Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not touch spilled material. Prevent entry into sewers, basements or confined

areas; dike if needed. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep locked up.. Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, metals, acids, alkalis.

Storage:
Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Splash goggles. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 200 STEL: 300 (ppm) from ACGIH (TLV) [United States] [1999] TWA: 150 STEL: 300 (ppm) [Australia] TWA: 590 STEL: 885 (mg/m3) from NIOSH TWA: 200 STEL: 300 (ppm) from NIOSH TWA: 590 STEL: 885 (mg/m3) [Canada] TWA: 200 STEL: 300 (ppm) from OSHA (PEL) [United States] TWA: 590 STEL: 885 (mg/m3) from OSHA (PEL) [United States] Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor:
Acetone-like Pleasant. Pungent. Sweetish. (Strong.)

Taste: Not available.

Molecular Weight: 72.12g/mole

Color: Clear Colorless.

pH (1% soln/water): Not available.

Boiling Point: 79.6 (175.3°F)

Melting Point: -86°C (-122.8°F)

Critical Temperature: 262.5°C (504.5°F)

Specific Gravity: 0.805(Water = 1)

Vapor Pressure: 10.3 kPa (@ 20°C)

Vapor Density: 2.41 (Air = 1)

Volatility: Not available.

Odor Threshold: 0.25 ppm

Water/Oil Dist. Coeff.: The product is more soluble in oil; log(oil/water) = 0.3

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, diethyl ether, acetone.

Solubility: Soluble in cold water, diethyl ether, acetone.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Heat, ignition sources, mechanical shock, incompatible materials.

Incompatibility with various substances: Reactive with oxidizing agents, metals, acids, alkalis.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Incompatible with chloroform, copper, hydrogen peroxide, nitric acid, potassium t-butoxide, 2-propanol, chlorosulfonic acid, strong oxidizers, amines, ammonia, inorganic acids, isocyanates, caustics, pyrindines. Vigorous reaction with chloroform +alkali.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Eye contact. Inhalation.

Toxicity to Animals:
WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE. Acute oral toxicity (LD50): 2737 mg/kg [Rat]. Acute dermal toxicity (LD50): 6480 mg/kg [Rabbit]. Acute toxicity of the vapor (LC50): 32000 mg/m3 4 hours [Mouse].

Chronic Effects on Humans:
MUTAGENIC EFFECTS: Mutagenic for bacteria and/or yeast. TERATOGENIC EFFECTS: Classified POSSIBLE for human. May cause damage to the following organs: gastrointestinal tract, upper respiratory tract, skin, eyes, central nervous system (CNS).

Other Toxic Effects on Humans: Hazardous in case of skin contact (irritant, permeator), of ingestion, of inhalation (lung irritant).

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: May cause birth defects based on animal dats. Embryotoxic and/or foetotoxic in animal.

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: Causes skin irritation. May be absorbed through the skin. Eyes: Causes eye irritation. Inhalation: Inhalation of high concentrations may cause central nervous effects characterized by headache, dizziness, unconsciousness, and coma. Causes respiratory tract irritation and affects the sense organs. May affect the liver and urinary system. Ingestion: Causes gastrointestinal tract irritation with nausea, vomiting and diarrhea. May affect the liver. Chronic Potential Health Effects: Chronic inhalation may cause effects similar to those of acute inhalation. Prolonged or repeated skin contact may cause defatting and dermatitis.

Section 12: Ecological Information

Ecotoxicity: Ecotoxicity in water (LC50): 3220 mg/l 96 hours [Fathead Minnow]. 1690 mg/l 96 hours [Bluegill].

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: CLASS 3: Flammable liquid.

Identification: : Ethyl methyl ketone UNNA: 1193 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
New York release reporting list: Methyl ethyl ketone Rhode Island RTK hazardous substances: Methyl ethyl ketone Pennsylvania RTK: Methyl ethyl ketone Minnesota: Methyl ethyl ketone Massachusetts RTK: Methyl ethyl ketone New Jersey: Methyl ethyl ketone California Director's list of Hazardous Substances: Methyl ethyl ketone TSCA 8(b) inventory: Methyl ethyl ketone TSCA 8(d) H and S data reporting: Methyl ethyl ketone: Effective: 10/4/82; Sunset: 10/4/92 SARA 313 toxic chemical notification and release reporting: Methyl ethyl ketone CERCLA: Hazardous substances.: Methyl ethyl ketone: 5000 lbs. (2268 kg)

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada):
CLASS B-2: Flammable liquid with a flash point lower than 37.8°C (100°F). CLASS D-2A: Material causing other toxic effects (VERY TOXIC).

DSCL (EEC):
R11- Highly flammable. R36/37- Irritating to eyes and respiratory system. S9- Keep container in a well-ventilated place. S16- Keep away from sources of ignition - No smoking. S25- Avoid contact with eyes. S33- Take precautionary measures against static discharges.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 3

Reactivity: 0

Personal Protection: h

National Fire Protection Association (U.S.A.):

Health: 1

Flammability: 3

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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